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EPA ALKALI SCRUBBING TEST FACILITY: LIMESTONE WET SCRUBBING TEST RESULTS

Michael Epstein, et al

Bechtel Corporation
San Francisco, California

January 1974

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The report describes test results through early 1/74 from a prototype lime/limestone scrubbing test facility for removing SO2 and particulates from flue gases. The facility consists of three parallel scrubbers--a venturi/spray tower, a Turbulent Contact Absorber (TCA), and a marble-bed scrubber--each able to treat a 10-Mw equivalent (30,000 acfm) of flue gas from a coal-fired boiler at TVA's Shawnee Station. The short-term (less than 1 day) limestone factorial tests, completed in 2/73, were conducted at high (6.0-6.2) scrubber inlet liquor pH. Longer term (about 500 hours) limestone reliability verification tests, completed in 9/73, were conducted at reduced (5.6-5.8) scrubber inlet liquor pH, to increase system reliability and limestone utilization. As of early 1/74, more than 1000 hours of a long-term limestone run on the TCA and more than 2000 hours of a long-term lime run on the venturi/spray tower system were completed. The objective of testing since 2/73 has been to identify the most economically attractive lime/limestone system operating conditions, consistent with reasonable performance.

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ABSTRACT

The report describes test results from a prototype lime/limestone scrubbing test facility for removing SO_2 and particulates from flue gases. The facility consists of three parallel scrubbers--a venturi/spray tower, a Turbulent Contact Absorber (TCA), and a Marble-Bed Absorber--each able to treat a 10-Mw equivalent (30,000 acfm) of flue gas from a coal-fired boiler at TVA's Shawnee Station. The short-term (less than 1 day) limestone factorial tests, completed in February 1973, were conducted at high (6.0-6.2) scrubber inlet liquor pH. Longer term (about 500 hours) limestone reliability verification tests, completed in September 1973, were conducted at reduced (5.6-5.8) scrubber inlet liquor pH, to increase system reliability and limestone utilization. As of early January 1974, more than 1000 hours of a long-term limestone run on the TCA and more than 2000 hours of a long-term lime run on the venturi/spray tower system were completed. The objective of testing since February 1973 has been to identify the most economically attractive lime/limestone system operating conditions, consistent with reasonable performance.

This report presents the results, through early January 1974, of limestone and lime reliability verification and long-term reliability testing at the Shawnee Prototype Facility.

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Section 1

SUMMARY

1.1 EPA SHAWNEE TEST FACILITY

The EPA Shawnee test facility consists of three parallel scrubber systems: (1) a venturi followed by a spray tower; (2) a Turbulent Contact Absorber (TCA); and, (3) a Marble-Bed Absorber. Each system is capable of treating approximately 10 Mw equivalent (30,000 acfm* @ 300°F) of flue gas containing 1800-4000 ppm sulfur dioxide and 2 to 5 grains/scf of particulates.

The object of the limestone short-term (less than 1 day) factorial tests is to determine the effect of independent variables (e.g., gas rate) on SO_2 removal for the scrubber systems. These tests were conducted at a scrubber inlet liquor pH range of from 6.0 to 6.3. The results of the limestone factorial tests have been presented in References 1 and 2.

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*Although it is the policy of the EPA to use the Metric System for quantitative descriptions, the British System is used in this report. Readers who are more accustomed to metric units are refferred to the conversion table in Appendix A.

The major objective of the limestone and lime longer-term (greater than 2 weeks) reliability verification tests is to define regions for reliable (e.g., freedom from scaling, plugging, erosion, corrosion, etc.) operation of the scrubber systems. The limestone reliability verification tests were conducted at reduced scrubber inlet liquor pH (5.6-5.9), in order to reduce sulfite scaling potential and increase limestone utilization (100x moles SO_2 absorbed/mole $CaCO_3$ added).

For the limestone verification runs on the venturi/spray tower system, SO_2 removals from 67-82 percent have been obtained, with an average limestone utilization of 68 percent, for pressure drops from 10 to 14.5 inches H_2O (9 inches H_2O across venturi). The venturi/spray tower runs showed that washing the demister from the underside (upstream) can be effective in reducing soft solids accumulations on the demister blades. However, some accumulation of solids has occured even with improved washing procedures. Spiral tip stainless steel nozzles have operated in the spray tower for over 2100 on-stream hours of limestone scrubbing without significant erosion. However, erosion was significant after an additional 2150 on-stream hours of lime scrubbing operation; of a total of 28 nozzles, 9 were severely eroded and 15 were considerably worn.

For the limestone verification runs on the three-bed TCA system, SO_2 removals from 77-88 percent have been obtained, with an average limestone utilization of 77 percent, for pressure drops from 6.5 to 10.5 inches H_2O (includes about 2 inches H_2O across Koch Flexitray). The TCA runs showed that the Koch Flexitray was effective in minimizing soft solids accumulations on the chevron demister blades at or below a superficial gas velocity of 8 ft/sec. Deposits of scale and soft solids continued to occur, however, and could have resulted in plugging during prolonged operation. Significant problems with the TCA scrubber system during the limestone reliability verification tests have been:

(1) Erosion and subsequent failure of the plastic spheres. Present sphere life is under 2000 hours.

(2) Erosion of wire mesh support grids. Sturdier support grids (parallel 3/8 inch rods) have been installed during subsequent long-term reliability testing.

(3) Plugging of the inlet gas duct at the hot gas/liquid interface. The hot flue gas is cooled with process slurry before entering the neoprene rubber lined TCA scrubber. The problem of soft-solids buildup in the cooling zone has been solved by careful selection of the proper size, orientation, location and number of cooling spray nozzles, and by careful selection of the sootblowing schedule.

(4) Plugging of the mist eliminator. Progress has been made in reducing the magnitude of this problem but it has not been completely resolved at this time.

For the limestone verification runs on the single-stage Marble-Bed system, SO_2 removals from 65-77 percent have been obtained, with an average limestone utilization of 67 percent, for pressure drops from 7.5 to 11 inches H_2O. A severe operating problem has been associated with the erosion of the bed spray nozzles and subsequent pluggage of the marble bed and demister. This system has not been operated long enough to have solved these problems.

The slurries contain substantial quantities of fly ash (approximately 40 weight percent of solids is fly ash). There is evidence based on preliminary information generated at the EPA-RTP pilot facility that the presence of fly ash accelerates erosion.

The slurry analytical data for the reliability verification tests has indicated that the process liquors are supersaturated with respect to sulfate. The sulfate supersaturation increases with decreasing effluent residence time and/or with decreasing percent solids. The dissolved solids concentrations have ranged from about 7000 ppm (clarifier only) to 18,000 ppm (clarifier with centrifuge or filter). The major component in the slurry liquor is chloride. The chlorides present in the coal are absorbed from the flue gas in the scrubber.

The objective of the long-term test is to operate continuously for four to six months. On October 24, 1973, a limestone long-term reliability test was begun on the TCA system. Based on the results of the reliability verification tests and the tests conducted at the EPA pilot facility in Research Triangle Park, the following conditions were chosen for the long-term test:

Gas Rate, acfm @ 300°F	25,000
Gas Velocity, ft/sec	9.8
Liquor Rate, gpm	1200
L/G, gal/mcf	64
Percent Solids Recirculated	15
Effluent Residence Time, min.	10
Total Pressure Drop, in. H_2O	8.5
Percent SO_2 Removal (controlled)	80-85

Three beds of spheres were used, with five inches of spheres/bed. The top bed used Universal Oil Products (UOP) supplied thermoplastic-rubber (TPR) spheres and the bottom two beds UOP supplied high density polyethylene (HDPE) spheres. A summary of the operating data for the test is as follows:

Percent Limestone Utilization	71
Inlet SO_2 Concentration, ppm	1600-4000
Scrubber Inlet pH Range	5.7-6.0
Scrubber Outlet pH Range	5.3-5.6
Percent Solids Discharged	42
Dissolved Solids, ppm	8000

After approximately 500 hours of operation the run was terminated, due to unusually heavy solids build-up on the underside of the Koch Flexitray, on the scrubber walls between the top bed and the Koch tray and on the demister blades. Also, numerous (over 200) half-spheres of the TPR spheres were found in the scrubber and slurry circulating system. Half-spheres of TPR were also found lodged in the TCA inlet slurry spray nozzles. It should be noted that the scrubber beds (and bottommost grid) were free of scale after the 500 hour operating period, as was expected. The HDPE spheres had lost from 8-14 percent of their original weight and the TPR spheres about 2.6 percent.

It is hypothesized that the soft solids accumulations below the Koch tray were due to the partial blockage of the TCA slurry inlet nozzles by the TPR half-spheres, which produced high pressure drops across the nozzles, resulting in excessive entrainment of fine slurry droplets. The partially blocked nozzles may have also contributed to a large degree to the mist eliminator pluggage, but excessive gas velocity is a contributing factor.

On November 22, 1973, a new TCA limestone long-term reliability test was begun. The TPR spheres in the top stage had been replaced with HDPE spheres. The run conditions were identical to those for the initial test, excepting that the gas velocity has been dropped to 8 ft/sec (20,500 acfm). The velocity was reduced, because more detailed investigation of previous reliability verification runs indicated that long-term reliability for the present Koch tray-demister configuration should not be expected at a gas velocity of 9.8 ft/sec. The operating data for this test was essentially the same as for the initial test.

After 1190 hours of operation the run was interrupted, in order to check the wear rate of the HDPE spheres in the three beds. Pressure drop across the chevron demister increased slightly during the initial 800 hours of operation, and during the last 400 hours increased more rapidly to a final level about 1.5 times the initial value of 0.18 inches H_2O. An inspection of the system showed that the general appearance of the scrubber was good, with only very slight scale on the scrubber walls and bar-grids. Heavy solids deposits, however, covered the inlet slurry spray nozzles and header and adjacent walls. Also a heavy, relatively uniform (about 1 inch thick) solids layer covered the underside of the Koch tray; approximately 5 percent of the valves were completely plugged. All four inlet slurry spray nozzles were partially plugged with debris, primarily with plastic covering from pipe insulation. Demister plugging was confined to the bottom two passes only, reducing the free flow area by about 15 percent.

As with the previous TCA run, it is hypothesized that the solids accumulations on the inlet slurry spray nozzles and header and on the underside of the Koch tray were primarily caused by partial blockage of the TCA slurry inlet nozzles by debris, which produced high pressure drops across the nozzles, resulting in excessive entrainment of fine slurry droplets. Also, the blocked nozzles may have been a major factor contributing to the demister pluggage observed. The next long-term limestone reliability test on the TCA will be conducted with a strainer in the recirculating slurry line to catch debris and with TPR spheres in all three beds.

An initial lime reliability verification test on the venturi/spray tower system at the Shawnee facility was begun on October 9, 1973. The test was conducted at a scrubber inlet liquor pH of 8.0, a total (venturi and spray tower) liquid-to-gas ratio of 96 gal/mcf. an effluent residence time of 12 minutes and a percent total solids recirculated of 8 percent. The lime utilization was approximately 90 percent and the SO_2 removal approximately 85 percent, with a pressure drop of 12.5 inches H_2O (9 inches H_2O in venturi included). The scrubber outlet pH was between 4.6 and 5.4.

After 2153 hours (3 months) of on-stream operation the lime test was terminated due to a rapid increase in demister pressure drop throughout the final month of operation. This period of operation represents the longest continous run for prototype or full-scale installations of lime/limestone scrubbing systems in the United States, to date. Inspection after shutdown showed that scale formation in the scrubber vessel was not sufficiently heavy to interfere with the gas flow. The mist eliminator was substantially blocked, partly by solids that had fallen down from the outlet duct work and partly by scale formation, mainly on the bottom (inlet) vanes. The rubber-lined shell of the spray tower was covered with from 1/8 to 3/8 inch thick sulfate scale. Also, about 3/16 inch thick sulfate scale was found in the rubber lined variable speed pumps. It should be noted that scale formation in the spray tower, circulating slurry piping and pumps did not prevent continual operation of the system or necessitate termination of the 3 month long lime reliability test. However, scale particles in nozzles and strainers required periodic maintenance.

It is hypothesized that the sulfate scale formation occurred, primarily, during the latter month of testing, when the clarifier and filter were used for solids dewatering (~47 percent solids discharged) and the calculated liquor sulfate saturation was about 190 percent (90 percent supersaturated). An earlier inspection of the system, after 666 hours of operation, revealed a relatively clean scrubber. During this early portion of the test the clarifier was used for solids dewatering and the percent solids discharged (~23 percent) was lower than desired; the calculated liquor sulfate saturation was 150 percent. The next long-term lime reliability test will be made under conditions intended to reduce recirculating liquor sulfate saturation and the accumulation of solids in the outlet ductwork.

During the factorial limestone testing, overall particulate removal efficiencies of 99.4 to 99.8 percent* were obtained for the Chemico venturi at a gas flow rate of 30,000 acfm (330°F) and liquid-to-gas ratios from 13 to 27 gal/mcf, with venturi plug pressure drops from 6 to 12 inches H_2O. For the spray tower, the removal efficiency was about 98.5 percent at a gas velocity of 4 ft/sec and a liquid-to-gas ratio of 40 gal/mcf. For the TCA scrubber with 5 grids and no spheres, the overall removal efficiencies were 98.6 to 99.8 percent at a gas velocity of 7.5 ft/sec and a liquid-to-gas ratio of 50 gal/mcf, with total pressure drops (includes Koch tray, demister and inlet duct) from 4 to 7 inches H_2O. The Marble-Bed scrubber gave an overall particulate removal efficiency range of 98.8 to 99.6 percent during the factorial limestone tests, at a gas velocity of 5 ft/sec and a liquid-to-gas ratio of 54 gal/mcf, with 12 inches H_2O total pressure drop.

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*For an average scrubber inlet grain loading of 3.5 grains/scf, a particulate removal of 99.0 percent would correspond to 0.07 lbs particulate discharged per 10^6 BTU.

A limited series of particulate removal tests on the TCA system was performed by EPA during the reliability verification limestone testing. Overall removal efficiencies of 98.7 to 99.9 percent were achieved at gas velocities from 8 to 10 ft/sec, liquid-to-gas ratios from 40 to 80 gal/mcf, and total pressure drops from 5.5 to 10 inches H_2O. The higher pressure drops generally gave higher overall removal efficiencies. For the submicron particles (0.11 to 0.99 microns), the efficiencies were 95 to 99 percent (increasing with particle size) at 9.8 inches H_2O total pressure drop, 93 to 95 percent at 7.6 inches H_2O, and 71 to 90 percent at 5.6 inches H_2O. Because of the limited number of tests, conclusions regarding submicron collection efficiency should be reserved until additional testing can be carried out. The inlet mass loadings during these tests were 2 to 3 grains/scf with a mass mean diameter of about 23 microns. The mass mean diameters for the outlet particles were about 0.5 to 0.75 microns, depending upon the pressure drops.

The pumps used for slurry service at the test facility are rubbed lined, variable speed, centrifugal pumps with Hydroseals or Centriseals. In general, the pumps have performed satisfactorily and, in general, the rubber linings have been found to be in excellent condition. Operation of the Moyno pumps (for makeup limestone and lime slurry service) has also been satisfactory.

The major problem with the induced draft fans at the facility has been high fan vibration. This problem has been controlled by (1) addition of shims to the bearings or replacement of bearings, (2) insulation of the fan housings, (3) welding balance weights onto the fan shrouds, and (4) adding additional bracing to the outboard pedestals.

The reheaters originally employed at the facility were fuel oil fired units with separate combustion air supply and with combustion occurring in the flue gas stream. Quenching of the flame by the cold (128°F) flue gas and subsequent formation of soot in the exiting flue gas were effectively reduced by providing an isolated combustion zone (stainless steel sleeves) in each reheater and by replacing the turbulent mixing type fuel oil nozzles with mechanical atomizing nozzles. These modifications performed at the test facility are acceptable as an expedience for operation. However, operation is still not consistent with the requirements for long-term sustained reliability.

The rubber linings (in the spray tower, TCA, Marble-Bed, process water hold tanks, pumps, circulating slurry piping and agitator blades) have been found, generally, to be in excellent condition. Essentially no erosion or deterioration has been noted, except slight wear on some of the rubber-coated agitator blades. Hairline cracks have been noted in the Flakeline glass lining on the effluent hold tanks and clarifiers. However, the cracks did not appear to penetrate the entire thickness of the lining.

The concentration of solids in the underflow of the larger (30 foot diameter) TCA clarifier approaches the expected final settled density of the sludge (about 40 percent by weight). However, periodic high solids carryover in the overflow continues to occur in the two smaller (20 foot diameter) venturi and Marble-Bed clarifiers. Also, the highest solids concentration in the underflow streams from these smaller units averages about 25 percent by weight.

Operation of the centrifuge had been satisfactory. The cake discharged contained 56-62 weight percent solids. However, severe erosion on the bowl and casing necessitated repair of the unit after about 1400 on-stream hours of operation.

Tests have indicated that the dewatering capability of the filter corresponds to 50-55 and 45-50 weight percent solids in the cakes from limestone and lime slurries, respectively. Cake discharge from the nylon filter cloth has been satisfactory without the use of mechanical equipment (scraper or wire). However, the useful life of the nylon and polypropylene filter cloths tested to-date is unsatisfactory.

Operating experience has been gained with two types of pH meters: (1) a Uniloc Model 320 in-line flow-through type and (2) a Uniloc

Model 321 submersible type. The performance of the in-line flow-through type meter has been unsatisfactory due to erosion of the glass cells by the slurry, their high rate of failure and the frequent plugging of the sample lines. For the submersible type pH meters, cell erosion, cell breakage and sample line pluggage have not been experienced during the approximately 1300 hours of operation.

Experience with the Ohmart radiation-type density meter indicates a loss of calibration in the range of about 1 to 2 percent per week. Also, the meter accuracy is affected by the accumulation of scale in the sample line which can be removed only during the scrubber shutdowns. The sample lines and the probes of the bubble-type (differential pressure) density meters plug frequently and require significant maintenance. However, these meters are accurate when clean and can be used to check the calibration of the radiation-type density meters. Dynatrol density cells (using the vibration principle of the U-tube for continuous response to density changes) have been installed to measure the densities of the lime slurry feed to the venturi/spray tower system and the circulating limestone slurry to the TCA system. The performance of the type of density meter has thus far been encouraging.

Operating experience with control valves in slurry service has generally been unsatisfactory. Severe erosion in a short time has been caused by the increasing velocity during throttling operation. This deterioration has been observed in the stainless steel plug valves, globe valves and rubber pinch valves. Satisfactory and trouble free flow control has been experienced only with variable speed pumps.

1.2 EPA PILOT FACILITY AT RESEARCH TRIANGLE PARK

Two pilot-scale TCA scrubber systems (400 acfm @ 300°F each) have been installed at the EPA facility in Research Triangle Park, N.C., in support of the Shawnee testing activities. The following conclusions have been drawn from the limestone and lime results of the TCA pilot-plant testing with inlet SO_2 feed concentrations of 3000 ppm:

- For limestone scrubbing, control of the scrubber effluent pH below 6.2 will prevent calcium sulfite scaling. However, this conclusion is based on tests run without chloride in the scrubbing liquor.
- Acceptable scrubber inlet pH (reasonable SO_2 removal and reasonable lime utilization) for lime scrubbing is in the 7-8 range.
- Limestone dissolution kinetics are improved by plug flow reaction; higher utilizations can be achieved by effluent hold tank designs such as U-tubes or a series of stirred tanks that approximate plug flow.
- For limestone scrubbing, dissolution of $CaCO_3$ is the rate controlling step for SO_2 absorption. For high-calcium lime scrubbing, dissolution of $CaSO_3$ is the rate controlling step.
- Hold tank residence time must exceed 5 minutes in a limestone system. 10 minutes appears to be a good choice. For a lime system, 5 minutes appears adequate.
- The scrubber effluent will always be supersaturated with $CaSO_4 \cdot 2H_2O$ when a scrubber is operated with saturated feed.
- Supersaturation is maximum at the first bed TCA support grid and rapid scaling of the grid by calcium sulfate occurs at liquid-to-gas ratios less than 65 gal/mcf with no fly ash in the system. The liquid-to-gas ratio must exceed 65 for reliable operation with saturated calcium sulfate feed.

- The presence of fly ash reduces the rate of scaling by calcium sulfate.
- Sulfate scaling can be eliminated by operating a scrubber in the unsaturated mode. Closed liquor loop unsaturated operation can be achieved in a chloride-free scrubber by reducing oxidation below 19 percent. Under these conditions the sulfate generated by oxidation is purged entirely as solid solution (i.e., calcium sulfate in calcium sulfite crystal lattice). Additional work is needed for a system with chlorides present in the process liquor, since all commercial systems will have chloride.
- For limestone scrubbing, oxidation is a controllable variable within the limits required for unsaturated operation. It can be reduced by eliminating air contact in the effluent hold tank (e.g., using sealed stirred tank or plug flow tank). Further reduction can be attained by circulating high percent solids (which affects the amount of liquor circulating through the clarifier or filter).
- Sulfate bound as solid solution is less soluble than the pure salt and, therefore, the potential for water pollution is reduced.
- The dolomitic component of limestone feeds is essentially inert and leaves the scrubber in the same form within the sludge.

Section 2

INTRODUCTION

In June 1968, the Environmental Protection Agency (EPA), through its Office of Research and Development (OR&D) and Control Systems Laboratory, initiated a program to test a prototype lime and limestone wet-scrubbing system for removing sulfur dioxide and particulates from flue gases. The system is integrated into the flue gas ductwork of a coal-fired boiler at the Tennessee Valley Authority (TVA) Shawnee Power Station, Paducah, Kentucky.

Bechtel Corporation of San Francisco is the major contractor and test director, and TVA is the constructor and facility operator.

Three major goals of the test program are: (1) to characterize as completely as possible the effect of important process variables on sulfur dioxide and particulate removal; (2) to develop mathematical models to allow economic scale-up of attractive operating configurations to full-size scrubber facilities; and, (3) to perform long-term reliability testing.

The test facility consists of three parallel scrubber systems: (1) a venturi followed by a spray tower; (2) a Turbulent Contact Absorber (TCA); and, (3) a Marble-Bed Absorber. Each system is capable of treating approximately 10 Mw equivalent (30,000 acfm @ 300°F) of flue gas containing 1800-4000 ppm sulfur dioxide and 2 to 5 grains/scf of particulates. Each system can be operated with any combination of clarifier/filter/pond or clarifier/centrifuge/pond for solids disposal. The test facility has been described in detail in References 1, 2 and 3.

The venturi scrubber (manufactured by Chemical Construction Co.) contains an adjustable throat that permits control of pressure drop under a wide range of flow conditions. Although a venturi is ordinarily an effective particulate removal device, gas absorption is limited (in limestone wet-scrubbing systems) by low slurry residence time. For this reason the after-absorber (spray tower) was included for additional absorption capability. The TCA scrubber (manufactured by Universal Oil Products) utilizes a fluidized bed of low density plastic spheres which are free to move between retaining grids. The Marble-Bed scrubber (supplied by Combustion Engineering Co.) utilizes a packing of 3/4-inch glass spheres (marbles). A "turbulent layer" of liquid and gas above the glass spheres enhances mass transfer and particulate removal. Figures 2-1, 2-2 and 2-3 (drawn roughly to scale) show the three scrubber systems along with the demisters selected for de-entraining slurry droplets in the gas stream.

The following sequential test blocks were defined for the program:

(1) Air/water testing

(2) Sodium carbonate testing

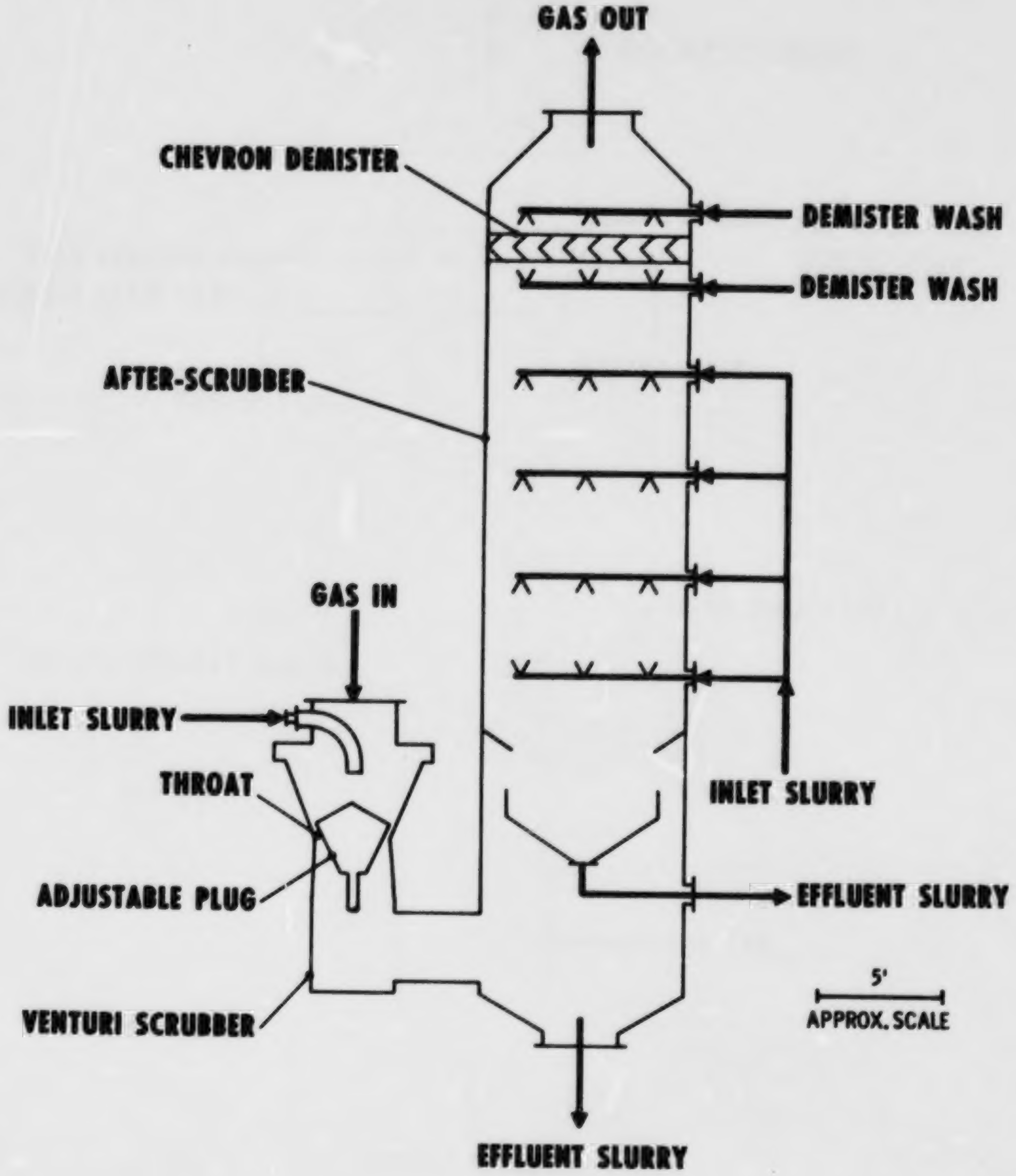
GAS OUT
CHEVRON DEMISTER
DEMISTER WASH
DEMISTER WASH
AFTER-SCRUBBER
GAS IN
INLET SLURRY
THROAT
INLET SLURRY
ADJUSTABLE PLUG
EFFLUENT SLURRY
VENTURI SCRUBBER
5'
APPROX. SCALE
EFFLUENT SLURRY

Figure 2-1. Schematic of Venturi Scrubber and Spray Tower

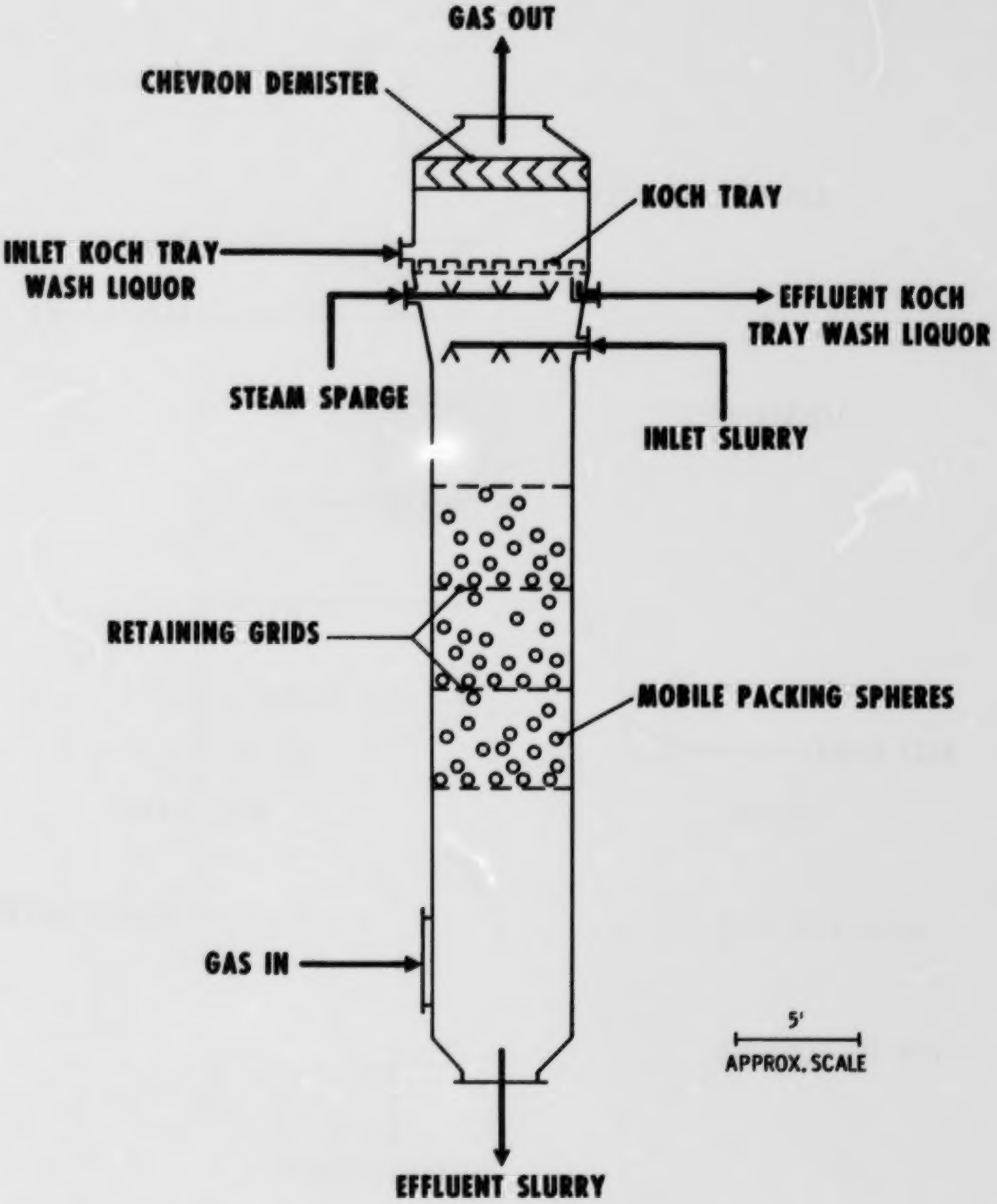
GAS OUT
CHEVRON DEMISTER
KOCH TRAY
INLET KOCH TRAY WASH LIQUOR
EFFLUENT KOCH TRAY WASH LIQUOR
STEAM SPARGE
INLET SLURRY
RETAINING GRIDS
MOBILE PACKING SPHERES
GAS IN
5'
APPROX. SCALE
EFFLUENT SLURRY

Figure 2-2. Schematic of Three-Bed TCA

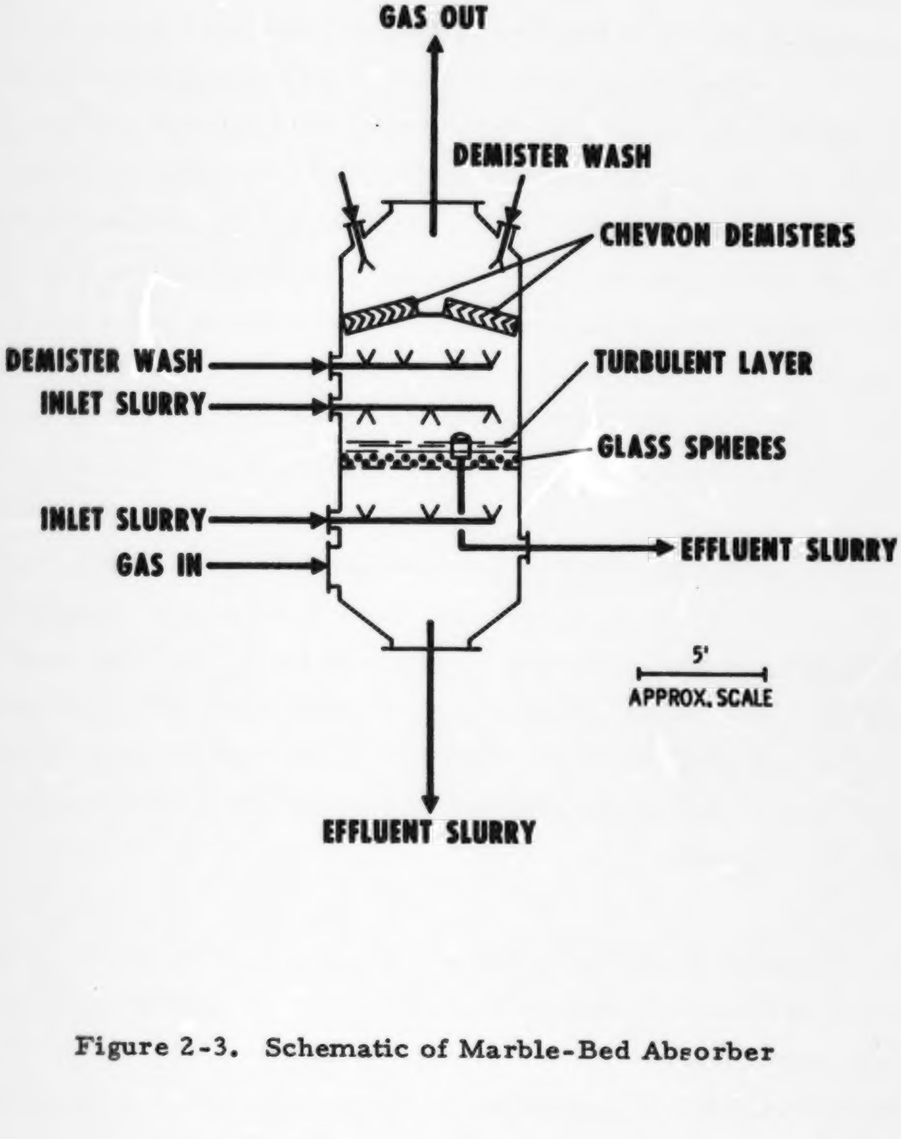
GAS OUT
DEMISTER WASH
CHEVRON DEMISTERS
DEMISTER WASH
INLET SLURRY
TURBULENT LAYER
GLASS SPHERES
INLET SLURRY
EFFLUENT SLURRY
GAS IN
5'
APPROX. SCALE
EFFLUENT SLURRY

Figure 2-3. Schematic of Marble-Bed Absorber

(3) Limestone wet-scrubbing testing
(4) Lime wet-scrubbing testing

The limestone and lime wet-scrubbing test blocks have been divided into three general catagories: (1) short-term (less than 1 day) factorial tests, (2) longer term (over 2 weeks) reliability verification tests, and (3) long-term (4 to 6 months) reliability tests. The object of the factorial tests is to determine the effect of independent variables (e.g. gas rate) on SO_2 removal for the scrubber systems. The primary objective of the reliability verification tests is to define regions for reliable (e.g. scale free) operation of the scrubber systems. The object of the reliability tests is to determine the long-term operating reliability for the scrubber systems and to develop more definitive process economics data and scale-up factors.

The test program schedule is presented in Figure 2-4. As can be seen in the figure, the air/water, sodium carbonate, limestone factorial and limestone reliability verification tests have been completed. As of early January 1974, a three month lime reliability verification test has been completed on the venturi/spray tower system, as well as seven weeks of a limestone reliability test on the TCA system.

Two smaller scrubbing systems (400 acfm @ 300°F each), which are capable of operating over a wide range of operating conditions, have been installed at the EPA facility in Research Triangle Park, North Carolina, in support of the Shawnee prototype testing activities.

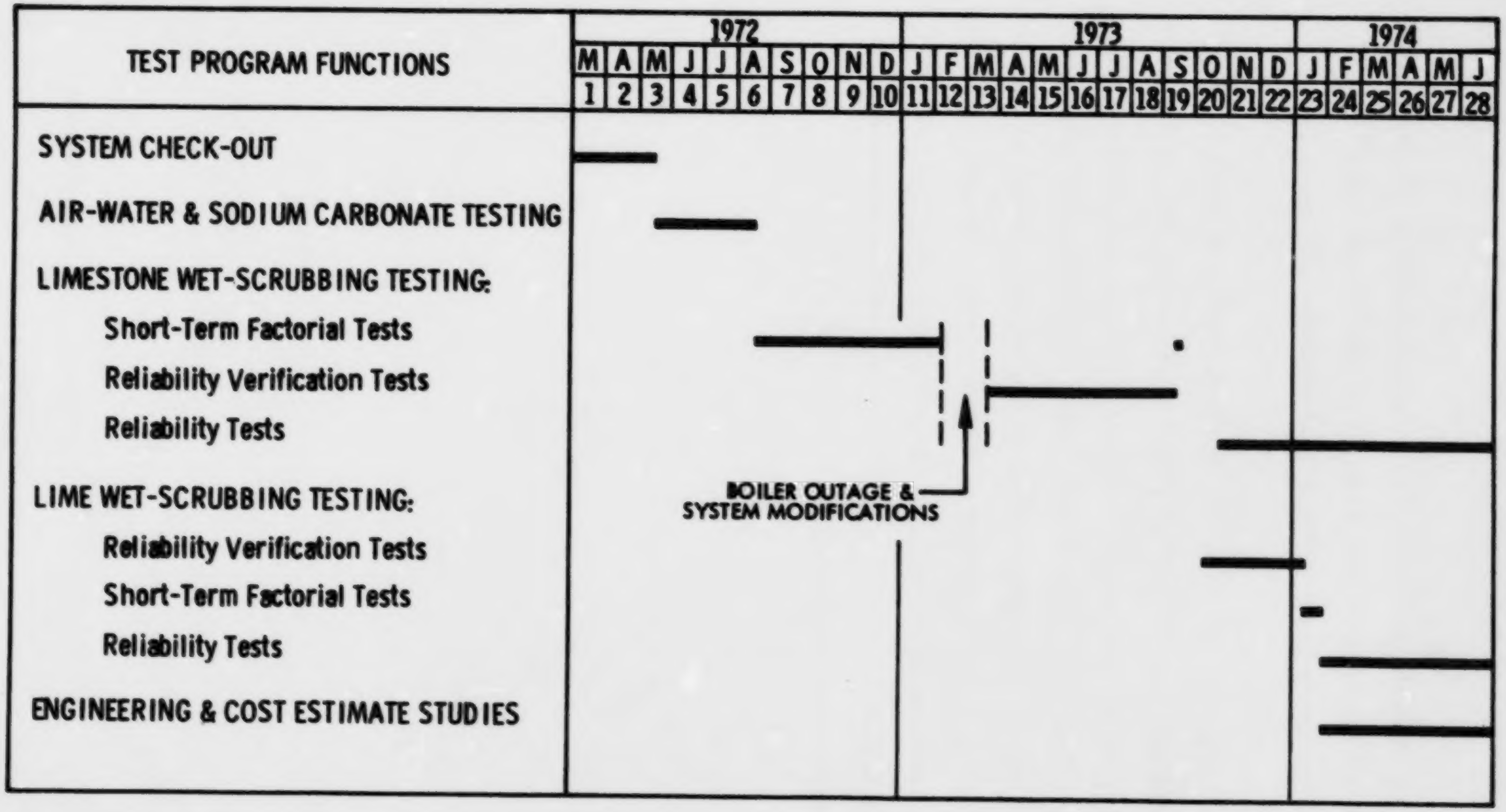

Figure 2-4. Shawnee Test Schedule

The small pilot scale scrubber systems are capable of simulating the TCA scrubber system and have generated large quantities of closed liquor loop data on certain TCA configurations.

This report presents the results, through early January 1974, of (1) limestone and lime reliability verification and long-term reliability testing at the Shawnee Prototype Facility, and (2) limestone and lime testing at the EPA Pilot Facility at Research Triangle Park. In Table 2-1, a description of the reports which are presently scheduled for general distribution is presented. Results from the air/water, sodium carbonate and limestone short-term factorial testing at the Shawnee facility have been presented in the August 1973 Topical Report (Reference 1), listed in Table 2-1.

Table 2-1

TOPICAL AND FINAL REPORT DESCRIPTION

Report Title	Information to be Included	Estimated General Publication Date
1. EPA Alkali Scrubbing Test Facility: Sodium Carbonate and Limestone Test Results	Summary of operational problems and resolutions, planned and actual test designs, results of air/water and Na_2CO_3 testing, utilization of data for model development, results of factorial limestone testing with interpretation of data.	August, 1973 (actual date)
2. EPA Alkali Scrubbing Test Facility: Limestone Wet-Scrubbing Test Results	Summary of operating problems and resolutions associated with reliability verification testing, planned and actual test design, interpretation of data, status of process model development and selection of parameters for limestone long-term reliability testing.	January, 1974 (actual date)
3. EPA Alkali Scrubbing Test Facility: Lime Wet-Scrubbing Test Results	Summary of operational problems and resolutions associated with lime reliability verification testing, planned and actual test designs, results of factorial lime testing, status of process model development, interpretation of data and status of limestone reliability testing.	April, 1974
4. EPA Alkali Scrubbing Test Facility: Final Report	Summary of total test program with particular emphasis on lime and limestone reliability test results, mathematical models, scale-up design and economic studies.	July, 1974

Section 3

LIMESTONE TEST RESULTS AT THE SHAWNEE FACILITY

Performance data from limestone reliability verification and long-term reliability testing at the Shawnee facility are presented in this section, along with an evaluation of each reliability verification test. Operating experience associated with specific system components (e.g., demisters, reheaters, SO_2 gas analyzers) will be discussed in detail in Section 4. Results from the limestone factorial tests have been presented in References 1 and 2.

3.1 RELIABILITY VERIFICATION LIMESTONE TESTING

The major objective of the closed liquor loop limestone and lime reliability verification tests is to identify areas or regions for reliable long term (4-6 month) operation consistent with reasonable SO_2 removal.

A majority of the reliability verification tests were on-stream for approximately 500 hours (3 weeks). It should be noted that, it is difficult to assess long-term reliability from runs lasting 500 hours, especially when small quantities of scale* or soft solids are present on system components.

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*In this report "scale" refers only to crystalline hard solids, and "solids" or "soft-solids" refer to mud-like slurry solids. "Plugging" refers to the accumulation of mud-like slurry solids.

Summaries of the limestone reliability verification test results for the venturi/spray tower, TCA and Marble-Bed systems are presented in Tables 3-1, 3-2, and 3-3, respectively. Operating data for Runs 506-1A (venturi/spray tower), 510-2A (TCA) and 506-3B (Marble-Bed) are graphically presented in Appendix B. Graphical presentation of the operating data for all of the limestone reliability verification runs will be included in the Final Report (see Table 2-1).

The significant data from the detailed inspection reports prepared at the test facility during the reliability verification tests are presented in Appendix C. The reliability data summarized in Tables 3-1, 3-2, and 3-3 have been obtained from the data in Appendix C.

3.1.1 System Reliability

Reliability verification tests presented in Tables 3-1, 3-2, and 3-3 has been evaluated in Tables 3-4, 3-5, and 3-6.

The major system problems addressed at the test facility are associated with scaling and plugging of the equipment. A majority of the component problems can be solved by improved design. The major variables affecting scaling and plugging tendencies are: (1) effluent residence time, (2) percent solids recirculated, (3) percent oxidation of sulfite to sulfate, (4) gas velocity, (5) liquid-to-gas ratio, and (6) scrubber pH.

The limestone reliability verification tests have been run at reduced scrubber inlet liquor pH (5.6-5.9) to decrease the potential for scaling and to increase limestone utilization. A modest reduction in SO_2 removal, from high-pH[*] performance, is the price of the increased system reliability and limestone utilization.

The test conditions for the initial reliability verification runs were selected in order to give maximum probability for reliable operation, consistent with reasonable SO_2 removal. Subsequent tests were made to observe the effects of reduced effluent residence time, reduced percent solids recirculated, increased gas velocity (decreased liquid-to-gas ratio) and increased scrubber inlet liquor pH on system reliability.[**] In addition, the effects of demister type (polypropylene vs. stainless) and demister wash location (upstream vs. upstream and downstream washing) were investigated in the venturi/spray tower system.

Venturi System. The initial venturi system test run 501-1A (see Tables 3-1 and 3-4) was conducted, as mentioned previously, under conditions selected to maximize the probability for reliable operation, i.e., an effluent residence time of 20 minutes, a percent solids recirculated of 15-16 percent[***] and a spray tower gas velocity of 5 ft/sec. As expected, the relative condition of the system at the end of the test was good (see Table 3-4). Subsequent venturi system runs were made at more economically attractive operating conditions, as mentioned previously. Run 507-1A (see Tables 3-1 and 3-4) indicated relatively

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[*] The limestone short-term factorial tests were run at a scrubber inlet liquor pH range from 6.0 to 6.3.

[**] Minimizing effluent residence time and percent solids recirculated, and maximizing gas velocity is, of course, economically attractive.

[***] Approximately 40 percent of solids is fly ash.

Table 3-1

SUMMARY OF LIMESTONE RELIABILITY VERIFICATION TESTS: VENTURI SYSTEM

Run No.	501-1A	502-1A	503-1A	506-1A
Test Objectives	Reliability verification test @ low pH with Chevron 316 S.S. demister.	Same as 501-1A with Chevron plastic demister.	Same as 502-1A with higher liquor rate and lower percent solids recirculated.	Same as 503-1A with higher gas rate and lower effluent residence time. Top and bottom demister wash. (e)
Start-of-Run Date	4/9/73	6/13/73	6/29/73	7/25/73
End-of-Run Date	5/9/73	6/26/73	7/11/73	8/13/73
On Stream Hours (a)	645	278	256	417
Gas Rate, acfm @ 330°F	20,000	20,000	20,000	30,000
Spray Tower Gas Vel., fps @125°F	5	5	5	7.5
Venturi/Spray Tower Liquor Rates, gpm	600/600	600/600	600/1200	600/1200
Spray Tower L/G, gal/mcf	40	40	80	53
Percent Solids Recirculated	15-16	14-16	8-9	8-10.5
Effluent Residence Time, min.	20	20	20	12
Stoichiometric Ratio, moles Ca/moles SO_2 absorbed	1.4-1.6(4/9-4/27) 1.9-2.1(4/27-5/9) (d)	1.5-1.9	1.4-1.6	1.4-1.6 (1.6-1.8 from 8/3-6) (f)(g)
Average % Limestone Utilization, 100x moles SO_2 absorbed/mole Ca	67 (4/9-4/27) 50(4/27-5/9) (d)	59	67	67 (59 from 8/3 to 8/6) (f)(g)
Inlet SO_2 Concentration, ppm	2,400-3,300	2,200-3,000	2,200-3,000	2,500-3,300 (2,000-2,200 on 7/26 & 28)
Percent SO_2 Removal	70-75	67-73	74-82	68-76
Scrubber Inlet pH Range	5.8-6.0	5.7-5.9	5.6-5.8	5.35-5.65
Scrubber Outlet pH Range	5.4-5.7	5.3-5.5	5.1-5.3	4.85-5.1
Percent Sulfur Oxidized	5-25	15-35	20-40	20-35
Solids Disposal System	Clarifier	Clarifier	Clarifier	Clarifier and centrifuge
Loop Closure, % Solids Disch.	20-28	21-39	27-41	55-65
Clear Liquor to Demister, gpm	14-20	14-20	27-33	40-55
Make-Up Water to Demister, gpm	12-14	12-14	10-12	8-11
Dissolved Solids, ppm	5,000-8,000	-	7,300	14,900 (i)
Total ΔP Range, in. H_2O (b)	10-11	10.0-10.5	10.4-11.6	12.5-14.5
Demister ΔP Range, in. H_2O	0.40-0.65	0.40-0.55	0.45-0.55	1.0-1.25 (h)
Demister Condition at End of Run (c) (e)	Scattered 1/8" scale on top and 20 mil scale on bottom.	1/16" scale on top. Light scale and solids between vanes. Approximately 1/3 ft^3 solids buildup at 4 locations (junction of support bars).	No scale or solids on top. 1/2 to 1" non-uniform scattered solids deposit on top of bottom vane and on 2nd pass of vane. Center portions clean.	Some plastic vanes damaged by chunks of solids broken off from outlet duct. 5 mil solids buildup on westside vanes. Moderate solids buildup on dead spots on support I beams & adjacent vanes.
Venturi and Spray Tower Conditions at End of Run	Thin scattered scale and eroded guidevane bolts in venturi section. Scattered 15-25 mil scale on after-scrubber walls above trapout tray. 9 of 28 slurry ST48FCN spray nozzles in after-scrubber were plugged.	5 mil scale on walls below plug and about 1/6 bolts heads on guidevanes in venturi section eroded. 10 mil scale on after-scrubber walls below trapout tray.	20 mil scale on walls below plug and noticeable erosion of guide-vane cross braces in venturi section. 15 mil scale on after-scrubber walls below trap-out tray. 3 of 28 slurry spray nozzles plugged.	15 mil scale on walls of flooded elbow & below plug. Cont'd erosion of guidevane cross braces. 20 mil light scattered scale on after-scrubber walls & spray headers. No signif. solids accum. above & below trap-out tray. Severe solids deposits in reheater outlet duct.

(a) Includes line-out.

(b) Spray tower and venturi, excluding demister.

(c) Chevron plastic four-pass open demister in all runs except 501-1A where Chevron 316 S.S. three-pass open demister was used.

(d) Reactivity of limestone decreased after 4/27 due to larger average limestone particle size.

(e) Demister was washed from bottom only for all runs except Run 506-1A where it was washed from both top and bottom.

(f) The stoichiometry range was higher at 1.6-1.8 (59% average limestone utilization) from 8/3 to 8/6 with correspondingly higher scrubber inlet pH range of 5.5 to 5.65.

(g) As of 7/27, a new limestone containing approx. 1.25 mole % $MgCO_3$ was used. Prior to this time a limestone having approx. 5 mole % $MgCO_3$ had been used.

(h) Range given is for period 7/25-8/8. Increased steadily from 1.25 to 1.40 in. H_2O after 8/8.

(i) Increasing steadily during run from 8,000 to 14,900 ppm.

Table 3-1 (Continued)

SUMMARY OF LIMESTONE RELIABILITY VERIFICATION TESTS: VENTURI SYSTEM

Run No.	507-1A	508-1A(h)
Test Objectives	Same as 506-1A with Chevron 316 S.S. demister with bottom wash only.	Same as 507-1A with top and bottom demister wash.
Start-of-Run Date	8/22/73	9/11/73
End-of-Run Date	9/9/73	9/12/73
On Stream Hours(a)	434	28
Gas Rate, acfm @ 330° F	30,000	30,000
Spray Tower Gas Vel., fps @125°F	7.5	7.5
Venturi/Spray Tower Liquor Rates, gpm	600/1200	600/1200
Spray Tower L/G, gal/mcf	53	53
Percent Solids Recirculated	8-10.5	10.5-11.5
Effluent Residence Time, min.	12	12
Stoichiometric Ratio, moles Ca/moles SO_2 absorbed	1.2-1.4 (1.4-1.75 from 8/31 to 9/7)(d)	1.3-1.5
Average % Limestone Utilization, 100x moles SO_2 absorbed/mole Ca	77 (63 from 8/31 to 9/7)(d)	71
Inlet SO_2 Concentration, ppm	2,400-3,400 (1,400-1,750, 8/31-9/3)	2,600-3,700
Percent SO_2 Removal	67-77	70-74
Scrubber Inlet pH Range	5.3-5.65	5.65-5.85
Scrubber Outlet pH Range	4.9-5.2	5.5
Percent Sulfur Oxidized	25-45(f)	20-28
Solids Disposal System	Clarifier and centrifuge(e)	Clarifier
Loop Closure, % Solids Disch.	53-68(e)	19
Clear Liquor to Demister, gpm	46-60(g)	33-57
Make-Up Water to Demister, gpm	6-11(g)	14-20
Dissolved Solids, ppm	16,300-18,800(e)	–
Total ΔP Range, in. H_2O(b)	13.5-14.5	13.5-14.0
Demister ΔP Range, in. H_2O	1.25-1.35	1.3-1.4
Demister Condition at End of Run(c)	5 mil solids deposit on all bottom vanes & 10 mil on all top vanes. In NE section: 2 ft^2 area 75% plugged (top), another 2 ft^2 25% plugged (top).	Approximately the same condition as at end of run 507-1A.
Venturi and Spray Tower Conditions at End of Run	Venturi operated without sootblower. 3-4" solids deposit on E&W quadrant of inlet duct walls upstream of plug & on bull nozzle feed pipe. < 5 mil scale on walls of venturi below plug & on flooded elbow.	Approximately the same condition as at end of run 507-1A, except heavy solids build-up in reheater outlet duct.

(a) Includes line-out.

(b) Spray tower and venturi, excluding demister.

(c) Chevron 316 S.S. three-pass open demister was used.

(d) High stoichiometry range of 1.4-1.75 (63% average limestone utilization) caused by excess limestone in scrubber slurry during the period of low inlet SO_2 concentration (av. 1600 ppm) from 8/31 through 9/3.

(e) Switched to clarifier only at 0930 hours on 8/31. Percent solids discharged was 20-30 wt. % and dissolved solids decreased gradually to 11,300 ppm (on 9/6) after 8/31.

(f) 50-75% oxidation from 8/31 through 9/3 when average inlet SO_2 concentration dropped to 1600 ppm.

(g) The flow ranges for clear liquor and makeup water were 34-53 and 15-21 gpm, respectively, from 8/31 to 9/9, when clarifier only was used.

(h) System shut down after 28 hours of operation due to system problems (i.e., high entrainment from demister top flush, pluggage of outlet DuPont SO_2 analyzer sample probes).

Table 3-2
SUMMARY OF LIMESTONE RELIABILITY VERIFICATION TESTS: TCA SYSTEM

Run No.	501-2A	502-2A	508-2A	509-2A
Test Objectives	Reliability verification test @ low pH.	Same as 501-2A with high stoichiometry and pH.	Replicate of 501-2A.	Same as 501-2A with lower percent solids recirc.
Start-of-Run Date	3/22/73	4/27/73	5/25/73	6/5/73
End-of-Run Date	4/23/73	5/21/73	5/29/73	6/25/73
On Stream Hours(a)	580	557	98	465
Gas Rate, acfm @ 300°F	20,000	20,000	20,000	20,000
Gas Velocity, fps @ 125°F	7.8	7.8	7.8	7.8
Liquor Rate, gpm	1200	1200	1200	1200
L/G, gal/mcf	80	80	80	80
Percent Solids Recirculated	14-16	14-16	15-16	8-9
Effluent Residence Time, min.	20	20	20	20
Stoichiometric Ratio, moles Ca/moles SO_2 absorbed	1.1-1.4	1.5-1.9 (2.1-2.7 from 5/5-12)(c)	1.2-1.4	1.2-1.45
Average % Limestone Utilization, 100x moles SO_2 absorbed/mole Ca	80	59 (42 from 5/5-12)(c)	77	75
Inlet SO_2 Concentration, ppm	2,200-3,300	2,300-3,300	2,300-3,000	2,000-3,100
Percent SO_2 Removal	80-86	90-97	82-87	80-88
Scrubber Inlet pH Range	5.6-6.0	5.9-6.1	5.6	5.5-5.8
Scrubber Outlet pH Range	5.1-5.7	5.4-5.7	5.0-5.2	5.0-5.4
Percent Sulfur Oxidized	20-40	17-35	20-35	32-50
Solids Disposal System	Clarifier	Clarifier	Clarifier	Clarifier
Loop Closure, % Solids Disch.	25-48	31-39	31-43	26-45
Clear Liquor to Koch Tray, gpm	20-30	5-20	5-18	20-45
Make-Up Water to Koch Tray, gpm	7-12	8-12	7-12	7-11
Dissolved Solids, ppm	4,000-10,000	4,300-8,800	–	8,300-11,800
Total ΔP Range, in. H_2O(b)	4.5-5.3	5.5-6.5(d)	5.0-6.0	5.0-5.8
Demister and Koch Tray ΔP Range, in. H_2O	1.6-2.0	1.9-2.2	1.9-2.3	1.9-2.0
Demister Condition at End of Run	1/16" scale on bottom vanes only.	1/16" scale on vanes. About 50% of west quadrant plugged.	Clean.	1/16" scale on west quadrant.
Bed Condition at End of Run	Spheres in middle bed fell down to lower bed due to 2 holes in bottom grid. Replaced 3 dozen collapsed spheres.	No grid failure but significant deterioration of grid wire continued.	Replaced about 5% of collapsed spheres. Replaced 3 damaged grid sections.	Replaced the damaged SW section of top grid. Replaced about 20% of collapsed spheres.
Inlet Duct Condition at End of Run	Slight solids built-up upstream and heavy solids buildup downstream of cooling nozzles.	About 60% of duct area plugged. Solids buildup at and upstream of nozzles.	Solids buildup upstream of cooling nozzles.	Clean.
Other Problems or Comments	9 intermediate shutdowns due to cooling nozzle and Ventri-Rod pluggage. Ventri-Rod pluggage ranged from 12-70%. Replaced Ventri-Rod with 4 ST24FCN SS Bete nozzles on 4/16/73.	4 intermediate shutdowns due to cooling nozzles pluggage. Used Spraco 7LB 316 SS nozzles on 5/5/73.	–	Modified soot-blower head on 5/29/73 to have 2 jets blowing air forward only. Capped bottom cooling spray nozzle.

(a) Includes line-out.

(b) Total, excluding demister and Koch Tray.

(c) Reactivity of limestone decreased during the period of higher stoichiometry range and lower average limestone utilization, due to larger average limestone particle size.

(d) Range given is for period before 5/15. Increased gradually from 6 to 9 in. H_2O from 5/15 to 5/21.

Table 3-2 (Continued)

SUMMARY OF LIMESTONE RELIABILITY VERIFICATION TESTS: TCA SYSTEM

Run No.	510-2A	514-2A	515-2A	
Test Objectives	Same as 509-2A with higher gas rate.	Same as 510-2A with lower effluent residence time and higher percent solids recirculated.	Same as 514-2A with lower percent solids recirculated.	
Start-of-Run Date	6/27/73	7/22/73	8/16/73	
End-of-Run Date	7/10/73	8/13/73	9/10/73	
On Stream Hours[a]	297	493	571	
Gas Rate, acfm @ 300°F	25,000	25,000	25,000	
Gas Velocity, fps @ 125°F	9.8	9.8	9.8	
Liquor Rate, gpm	1200	1200	1200	
L/G, gal/mcf	64	64	64	
Percent Solids Recirculated	7.5-9.5	13.5-16	7.0-8.5	
Effluent Residence Time, min.	20	4.4	4.4	
Stoichiometric Ratio, moles Ca/moles SO_2 absorbed	1.2-1.5	1.25-1.55(7/22-8/5) 1.15-1.3(8/6-13)[g]	1.2-1.4(1.4-1.55 from 8/31 to 9/3)[c]	
Average % Limestone Utilization, 100x moles SO_2 absorbed/mole Ca	74	71 (7/22-8/5) 82 (8/6-13)[g]	77 (68 from 8/31 to 9/3)[c]	
Inlet SO_2 Concentration, ppm	2,000-2,700	2,100-3,100(1,800-2.100, 7/24, 26 & 28)	2,400-3,300(1,450-1,700, 8/31-9/3)	
Percent SO_2 Removal	78-89	77-89	80-88	
Scrubber Inlet pH Range	5.4-5.5	5.2-5.55	5.2-5.4	
Scrubber Outlet pH Range	4.85-5.2	4.7-5.0	4.9-5.1	
Percent Sulfur Oxidized	35-55	20-50	25-50[d]	
Solids Disposal System	Clarifier	Clarifier	Clarifier[e]	
Loop Closure, % Solids Disch.	26-44	27-52	34-44[e]	
Clear Liquor to Koch Tray, gpm	25-45	5-26	36-50	
Make-Up Water to Koch Tray, gpm	9-13	9-13	10-12	
Dissolved Solids, ppm	8,800-11,300	9,800-11,400	11,000-13,300[f]	
Total ΔP Range, in. H_2O[b]	6.6-7.6	7.0-8.5	7.0-8.5	
Demister and Koch Tray ΔP Range, in. H_2O	2.2-2.5	2.2-2.5 (2.5-2.8 from 8/10 to 8/13)	2.2-2.5 (2.5-2.9 from 9/6 to 9/10)	
Demister Condition at End of Run	60 mil scale on most of demister. 3 of 14 sections in SW corner were partially plugged with 1/2" solids between bottom vanes.	20% area plugged with solids. NW quadrant had higher buildup (50% plugged) with hard cryst. solids. Solids buildup mainly on bottom vanes. Pitting continued.	40% area plugged. Solids buildup mainly on bottom 2 vanes. Up to 1" solids buildup on underside of Koch tray. 6 tray valves partially plugged.	
Bed Condition at End of Run	Several loose grid wires. No grid replacement needed.	14% damaged spheres in lower 2 beds. Light scale on 75% of bottom grid.	Broken grid wires.[h] 2-3" stalactite on btm. grid. 1/32-3/16" scale on walls.	
Inlet Duct Condition at End of Run	Clean.	7 ft^3 solids buildup upstream of nozzles.	Clean.	
Other Problems or Comments	–	As of 7/27 a new limestone having ~ 1.25 mole % $MgCO_3$ was used. Prior to this time, limestone containing ~ 5 mole % $MgCO_3$ was used.	Underside of Koch tray not properly washed due to loose steam sparger branch headers.	

(a) Includes line-out.

(b) Total, excluding demister and Koch tray.

(c) High stoichiometry range of 1.4-1.55 (68% average limestone utilization) caused by excess limestone in scrubber slurry during the period of low inlet SO_2 concentration (av. 1600 ppm) from 8/31 through 9/3.

(d) 48-80% oxidation from 8/31 through 9/3 when average inlet SO_2 concentration dropped to 1600 ppm.

(e) With clarifier and centrifuge before 1235 hours on 8/20. Percent solids discharged from centrifuge was 58-59%.

(f) No analytical data before 8/20, when clarifier and centrifuge were used.

(g) Indicates effect of utilization of new limestone (see Other Problems or Comments).

(h) About 6 in^2 of support grid for top bed broken. Some of top bed spheres dropped into middle bed.

Table 3-3

SUMMARY OF LIMESTONE RELIABILITY VERIFICATION TESTS: MARBLE-BED SYSTEM

Run No.	501-3A & 3B	502-3A	503-3A & 3B	504-3A & 505-3A
Test Objectives	Reliability verification test @ low pH.	Same as 501-3A & 3B with high stoichiometry & pH.	Same as 501-3A & 3B with lower percent solids recirc.	Same as 501-3A & 3B with Spraco bed spray nozzles.
Start-of-Run Date	3/14/73	4/25/73	5/11/73	5/25/73
End-of-Run Date	4/23/73	5/7/73	5/22/73	6/4/73
On Stream Hours(a)	771	285	267	233
Gas Rate, acfm @ 330°F	20,000	20,000	20,000	20,000
Gas Velocity, fps @ 125°F	5.1	5.1	5.1	5.1
Liquor Rates to Top/Bottom Sprays, gpm	200/600	200/600	200/600	200/600
L/G, gal/mcf	53	53	53	53
Percent Solids Recirculated	10-12	11-14	8-11	10-12
Effluent Residence Time, min.	30	30	30	30
Stoichiometric Ratio, moles Ca/moles SO_2 absorbed	1.15-1.45(3/14-4/7) 1.3-1.6 (4/8-23)(g)	1.5-2.1 (4/25-29) 1.9-2.7(4/29-5/7)(d)	1.8-2.4	1.5-2.0
Average % Limestone Utilization, 100x moles SO_2 absorbed/mole Ca	77 (3/14-4/7) 69 (4/8-23)(g)	56 (4/25-29) 43 (4/29-5/7)(d)	48	57
Inlet SO_2 Concentration, ppm	2,500-3,300	2,600-3,200	2,500-3,500	2,300-3,100
Percent SO_2 Removal	65-71	67-77	67-71	67-72
Scrubber Inlet pH Range	5.8-6.0	5.8-6.1	5.7-5.9	5.6-5.8
Scrubber Outlet pH Range (Weir/Downcomer)	5.4-5.7/ 5.4-5.7	5.4-5.7/ –	5.4-5.7/ 5.1-5.3	5.3/ 5.2-5.4
Percent Sulfur Oxidized	15-35	10-30	15-30	10-30
Solids Disposal System	Clarifier	Clarifier	Clarif. & centrifuge	Centrifuge(e)
Loop Closure, % Solids Disch.	20-29	19-25	57-60 (used venturi clarifier 5/16-17)	60-65 (23-24 from 5/30-31)(e)
Clear Liquor to Demister, gpm	10-22	13-23	43-53	20-30
Make-Up Water to Demister, gpm	8-12	7-20	3-5	3-4
Dissolved Solids, ppm	6,900-8,900	3,700-8,000	11,000(c)	10,500(f)
Total ΔP Range, in. H_2O(b)	8.5-10.5	7.5-11.0	8.0-9.3	8.3-9.7
Demister ΔP Range, in. H_2O	0.17-0.25	0.16-0.35	0.15-0.22	0.15-0.17
Demister Condition at End of Run	1/8" solids deposit bottom side.	1/4" slurry scale and some scale on top vanes of demister.	1/8" solids deposit on top side. Light, dust deposit on bottom side of demister.	50-60 mil scale on top vanes only.
Bed Condition at End of Run	30% of bed either plugged or marbles in stratified pattern.	60% of marbles stratified. 1 ft^2 area was plugged with solids.	25% of bed was plugged with solids and had stratified rows of marbles.	12% of bed plugged with solids. 60% of bed had stratified rows of marbles.
Inlet Duct Condition at End of Run	2 ft^3 of solids deposit between spray header and scrubber.	6 ft^3 of solids deposit blocking 60-70% of duct between header and scrubber.	1-1/2 ft^3 of solids deposit between header and scrubber.	1 ft^3 of solids deposit between header and scrubber.
Other Problems or Comments	Both soot blower airjets projecting forward. Several shutdowns due to plugged cooling and bottom spray nozzles. Swirl vanes in 13 of 16 CE bottom bed spray nozzles eroded away.	4 ST20FCN cooling spray nozzles replaced by ST24FCN nozzles at start of run. Swirl vanes in all 16 CE bottom bed nozzles disappeared. Swirl vanes in all 6 CE top bed nozzles lightly eroded.	2 cooling spray nozzles were found plugged. All CE bottom bed nozzles operated without swirl vanes. Swirl vanes in CE top bed nozzles still intact.	All 22 CE bed spray nozzles replaced by Spraco No. 1736 ramp bottom nozzles at start of run.

(a) Includes line-out.

(b) Total, excluding demister.

(c) Increasing steadily during run from 4,000 to 11,000 ppm, except for a brief decreasing period caused by use of venturi clarifier alone from 5/16 to 5/17.

(d) High stoichiometry range of 1.9 to 2.7 (43% average limestone utilization) caused by decreased limestone reactivity (i.e., larger average particle size).

(e) Used clarifier along from 5/30 - 5/31.

(f) Only one sample was taken during run.

(g) High stoichiometry range of 1.3 - 1.6 (69% average limestone utilization) caused by system degradation (i.e., erosion of slurry spray nozzles and marble bed pluggage).

Table 3-3 (Continued)

SUMMARY OF LIMESTONE RELIABILITY VERIFICATION TESTS: MARBLE-BED SYSTEM

Run No.	506-3B
Test Objectives	Same as 505-3A with bed under spray nozzles raised higher.
Start-of-Run Date	6/15/73
End-of-Run Date	7/2/73
On Stream Hours[a]	380
Gas Rate, acfm @ 330°F	20,000
Gas Velocity, fps @ 125°F	5.1
Liquor Rates to Top/Bottom Sprays, gpm	200/600
L/G, gal/mcf	53
Percent Solids Recirculated	9-11
Effluent Residence Time, min.	30
Stoichiometric Ratio, moles Ca/moles SO_2 absorbed	1.6-2.1
Average % Limestone Utilization, 100x moles SO_2 absorbed/mole Ca	54
Inlet SO_2 Concentration, ppm	2,100-3,200
Percent SO_2 Removal	65-71
Scrubber Inlet pH Range	5.5-5.8
Scrubber Outlet pH Range (Weir/Downcomer)	5.5-5.6/ 5.0-5.2
Percent Sulfur Oxidized	20-40
Solids Disposal System	Centrifuge
Loop Closure, % Solids Disch.	60-66
Clear Liquor to Demister, gpm	24-30
Make-Up Water to Demister, gpm	4-6
Dissolved Solids, ppm	15,500-20,000
Total ΔP Range, in. H_2O[b]	7.8-9.0
Demister ΔP Range, in. H_2O	0.17-0.20[c]
Demister Condition at End of Run	1/3 of the demister (particularly SE corner) completely plugged.
Bed Condition at End of Run	10% of bed plugged. 15% of marbles stratified.
Inlet Duct Condition at End of Run	Extremely light solids accumulation at duct walls downstream of nozzles.
Other Problems or Comments	One shutdown due to reheater pilot malfunction. One shutdown due to instrument air compressor valve leakage. Extended cooling spray nozzles to reach 2" from scrubber inlet.

(a) Includes line-out.

(b) Total, excluding demister.

(c) Range given is for period before 6/23. Increased steadily from 0.20 to 0.80 in. H_2O from 6/23 to 7/2.

Table 3-4

LIMESTONE RELIABILITY VERIFICATION TEST RUN EVALUATIONS: VENTURI AND SPRAY TOWER

PARAMETER	TEST RUN							
	501-1A (645 Operating Hours)		502-1A (278 Operating Hours)		503-1A (256 Operating Hours)		506-1A (417 Operating Hours)	
	Comments	Relative Condition at End-of-Run	Comments	Relative Condition at End-of-Run	Comments	Relative Condition at End-of-Run	Comments	Relative Condition at End-of-Run
Demister Scaling or Plugging	Light scale on bottom vanes. Scattered scale on top vanes. Negligible solids deposits.	Fair	Moderate scale on top vanes. Scattered light solids deposits on bottom vanes at support bar junctions.	Fair	No scale. Non-uniform, light, scattered solids deposits on bottom two rows of vanes.	Good	No scale. Moderate solids deposits around support I beams. About 10% of plastic top vanes damaged by solids dislodged from stack (Solids due to high entrainment of demister top flush).	Poor
Venturi and Spray Tower Mechanical Condition at End of Run	Slight erosion of guide vane bolts and surrounding area in venturi.	Fair	Moderate erosion of guide vanes, bolts and cross braces in venturi.	Fair	Slight erosion of guide vane cross braces in venturi.	Fair	Slight erosion in guide vane area of venturi. Slight erosion of top splash seal flange in venturi.	Fair
Venturi Scaling or Plugging	Scattered light scale on walls below plug. Moderate scale on walls of flooded elbow. Negligible solids deposits.	Good	Negligible scale on walls below plug. Moderate scale on walls of flooded elbow. Negligible solids deposits.	Good	Light scale on walls below plug. Moderate scale on walls of flooded elbow. Negligible solids deposits.	Good	Light scale on walls below plug and on walls of flooded elbow. Negligible solids deposits.	Good
Spray Tower Scaling or Plugging	Scattered light scale on walls. Scattered moderate solids deposits on top slurry header, on bottom demister wash header, and on bottom of trapout tray.	Good	Light scale on walls below trapout tray. Scattered light solids deposits on top slurry header, on bottom demister wash header, and on bottom of trapout tray.	Good	Light scale on walls below trapout tray. Light solids deposits on bottom of trapout tray.	Good	Light scale on all four spray headers and on about 50% of wall area above trapout tray. Light solids on bottom of trapout tray and adjacent walls.	Fair

Table 3-4 (Continued)

LIMESTONE RELIABILITY VERIFICATION TEST RUN EVALUATIONS: VENTURI AND SPRAY TOWER

PARAMETER	TEST RUN			
	507-1A (434 Operating Hours)		508-1A (28 Operating Hours)	
	Comments	Relative Condition at End-of-Run	Comments	Relative Condition at End-of-Run
Demister Scaling or Plugging	No scale. Negligible solids deposits on vanes. Scattered partial plugging of about 8% of top vane flow area.	Good	No scale. Negligible solids deposits. High entrainment of demister top flush.	Poor
Venturi and Spray Tower Mechanical Condition at End of Run	Slight erosion of guide vane assembly.	Fair	—	—
Venturi Scaling or Plugging	No scale. Moderate solids buildup at wet-dry interface due to discontinued soot blowing.	Good	—	—
Spray Tower Scaling or Plugging	Negligible scale and solids deposits.	Good	—	—

Table 3-5

LIMESTONE RELIABILITY VERIFICATION TEST RUN EVALUATIONS: TCA

PARAMETER	TEST RUN							
	501-2A (580 Operating Hours)		502-2A (553 Operating Hours)		508-2A (98 Operating Hours)		509-2A (465 Operating Hours)	
	Comments	Relative Condition at End-of-Run	Comments	Relative Condition at End-of-Run	Comments	Relative Condition at End-of-Run	Comments	Relative Condition at End-of-Run
Demister and Koch Tray Scaling or Plugging	Negligible scale and solids deposits.	Good	Light scale on vanes. About 15% of bottom vane flow area plugged by solids.	Poor	Negligible scale and solids deposits.	Good	Moderate scale on bottom two rows of vanes. Negligible solids deposits.	Good
Scrubber Mechanical[a] Condition at End of Run	Spheres from middle bed dropped to bottom bed through eroded grid wires.	Bad	Significant erosion of grid wires.	Bad	Loose, bent and eroded wires in two grids.	Bad	Broken and eroded wires in several grids.	Bad
Scrubber Scaling or Plugging	Negligible scale. Scattered solids deposits on walls below Koch tray.	Good	Negligible scale. Some solids deposits on slurry nozzles only.	Good	Negligible scale. Scattered moderate solids deposits on walls immediately below Koch tray.	Fair	Moderate scale on walls below bottom bed, light scale on walls of bottom two beds. Negligible solids deposits.	Fair
Inlet Duct Plugging	Slight solids buildup upstream and heavy solids buildup downstream of cooling sprays.	Bad	About 60% of duct area plugged immediately upstream of cooling sprays.	Bad	Moderate solids buildup upstream of cooling sprays.	Poor	Clean	Excellent

[a] No attempt was made to modify run conditions in order to solve the continuing problem of support grid erosion. The wire mesh grids (0.148 inch diameter wires) were replaced with sturdier 3/8 inch diameter rods (1 - 1/4 inch on center) prior to the long-term reliability test.

Table 3-5 (Continued)

LIMESTONE RELIABILITY VERIFICATION TEST RUN EVALUATIONS: TCA

PARAMETER	TEST RUN					
	510-2A (297 Operating Hours)		514-2A (493 Operating Hours)		515-2A (571 Operating Hours)	
	Comments	Relative Condition at End-of-Run	Comments	Relative Condition at End-of-Run	Comments	Relative Condition at End-of-Run
Demister and Koch Tray Scaling or Plugging	Moderate scale on bottom vanes. About 25% of bottom vanes partially plugged with solids.	Fair	Flow area of bottom two vanes about 20% plugged with scale and solids (one quadrant about 50% plugged with hard crystalline solids.	Poor	Flow area of bottom two vanes about 40% plugged with scale and solids. Moderate solids buildup on underside of Koch tray, partially plugging several valves.	Bad
Scrubber Mechanical[a] Condition at End of Run	Loose and bent wires in several grids.	Bad	Loose, bent and broken wires in two middle grids.	Bad	Spheres from top bed dropped to middle bed through eroded grid wires.	Bad
Scrubber Scaling or Plugging	Scattered moderate to heavy scale on walls below bottom bed. Intermittent heavy scale on about 30% of bottom grid. Light scale on walls above bottom bed. Negligible solids deposits.	Poor	Light scale on bed walls. Heavy scale on 75% of bottom grid. Moderate scale and heavy solids on walls below Koch tray. Moderate scattered solids on walls below bottom bed.	Poor	Moderate scale between bottom bed and Koch tray. Heavy scale below bottom bed and on bottom grid. Intermittent heavy solids-scale deposits below bottom grid.	Bad
Inlet Duct Plugging	Clean	Excellent	Moderate solids buildup upstream of cooling sprays.	Fair	Clean	Excellent

(a) No attempt was made to modify run conditions in order to solve the continuing problem of support grid erosion. The wire mesh grids (0.148 inch diameter wires) were replaced with sturdier 3/8 incl. diameter rods (1 - 1/4 inch on center) prior to the long-term reliability test.

Table 3-6

LIMESTONE RELIABILITY VERIFICATION TEST RUN EVALUATIONS: MARBLE-BED ABSORBER

PARAMETER	TEST RUN							
	501-3A & 3B (771 Operating Hours)		502-3A (285 Operating Hours)		503-3A & 3B (267 Operating Hours)		504-3A & 505-3A (233 Operating Hours)	
	Comment	Relative Condition at End-of-Run	Comment	Relative Condition at End-of-Run	Comment	Relative Condition at End-of-Run	Comment	Relative Condition at End-of-Run
Demister Scaling or Plugging	Light scale on all vanes. Intermittent, moderate solids deposits on bottom vanes.	Fair	Moderate scale and solids deposits on top vanes. Light scale on bottom vanes.	Fair	No scale. Light solids deposits on top vanes.	Good	Moderate scale on top vanes. Light solids deposits on bottom vanes.	Fair
Scrubber Mechanical Condition at End of Run	Swirl vanes in 80% of bottom slurry nozzles completely eroded. Nozzle plugging by marbles dropped through loose grid.	Bad	All bottom slurry nozzles without swirl vanes.	Bad	About 20% of bottom slurry nozzles plugged with debris.	Bad	About 35% of bottom Spraco slurry nozzles partially plugged with marbles.	Poor
Scrubber Scaling or Plugging	Light scale on walls below bed. Intermittent heavy solids deposits on bottom spray headers & bottom of bed. About 30% of bed plugged or in stratified pattern.	Bad	Light scale on walls above and below bed and on all spray headers. About 2% of bed plugged, 60% stratified.	Poor	Light, intermittent scale-solids deposits on headers and walls above bed. Moderate scale-solids deposits on bottom headers. About 25% of bed plugged.	Bad	Moderate scale on walls above demister and bed. Scattered, light scale-solids deposits on headers below bed. About 12% of bed plugged, 60% stratified.	Bad
Inlet Duct Plugging	About 25% of duct plugged downstream of cooling sprays.	Bad	About 70% of duct plugged immediately downstream of cooling sprays.	Bad	About 20% of duct plugged downstream of cooling sprays.	Poor	About 30% of duct plugged downstream of cooling sprays.	Bad

Table 3-6 (Continued)

LIMESTONE RELIABILITY VERIFICATION TEST RUN EVALUATIONS: MARBLE-BED ABSORBER

PARAMETER	TEST RUN	
	506-3B (380 Operating Hours)	
	Comments	Relative Condition at End-of-Run
Demister Scaling or Plugging	Light scale on bottom vanes. Moderate scale on top vanes. About 30% of middle vanes completely plugged, 30% partially plugged.	Bad
Scrubbing Mechanical Condition at End of Run	About 80% of bottom Spraco slurry nozzles severely eroded	Bad
Scrubber Scaling or Plugging	Moderate scale on walls throughout scrubber. Intermittent, heavy scale on all headers and walls below bottom headers. About 10% of bed plugged, 15% stratified.	Bad
Inlet Duct Plugging	About 45% of duct plugged downstream of cooling sprays. No solids downstream of open nozzle.	Bad

good system condition at the end of 434 operating hours at an effluent residence time of 12 minutes, a percent solids recirculated of approximately 9 percent, a spray tower gas velocity of 7.5 ft/sec and a liquid-to-gas ratio of 53 gal/mcf. Effluent residence times below 12 minutes could not be obtained during the testing due to system constraints.

The venturi/spray tower runs also showed that washing the demister from the underside (upstream) can be effective in reducing the rate of soft solids accumulations on the demister blades, at demister superficial velocities at or below 7.5 ft/sec (see Runs 503-1A and 507-1A in Tables 3-1 and 3-4). In addition, the runs showed that washing the demisters from the topside (downstream) can cause droplet entrainment within the exiting high velocity flue gas and resultant accumulation of solids on the walls of the outlet duct (see Runs 506-1A, 507-1A and 508-1A). Demister operability will be discussed in greater detail in Section 4.2.

The spray tower has used spiral tip Bete No. ST-48 FCN stainless steel full cone nozzles for the duration of the reliability verification tests. No significant erosion of these nozzles had been observed for over 2000 hours of operation.

TCA System. As expected, the relative system condition at the end of the initial TCA reliability verification test 501-2A was good, as far as scrubber or demister scaling and plugging was concerned (see Tables 3-2 and 3-5). There was, however, difficulty experienced due to mechanical failure of a TCA support grid and pluggage of the inlet duct at the hot gas-liquid interface. During subsequent tests (see Runs 509-2A through 515-2A), the problem of inlet duct plugging was apparently solved, although there was still some accumulation of solids in the inlet duct during Run 514-2A (the resolution of the inlet duct plugging problem will be discussed in Section 4.3). The continual problem of erosion of TCA support grid wires was not solved during the remainder of the reliability verification tests. Sturdier support grids (parallel 3/8-inch rods) have been installed in the TCA scrubber during subsequent long-term testing.

The results of the subsequent testing, under more economically attractive operating conditions, showed relatively good system condition after 465 on-stream hours with an effluent residence time of 20 minutes, a percent solids recirculated of approximately 9 percent, a gas velocity of 7.8 ft/sec and a liquid-to-gas ratio of 80 gal/mcf (see Run 509-2A). A subsequent test at a gas velocity of 9.8 ft/sec and a liquid-to-gas ratio of 64 gal/mcf (Run 510-2A) gave some indication of scale buildup within the scrubber and partial pluggage of the demister. Two final test runs at an effluent residence time of 4.4 minutes (Runs 514-2A and 515-2A) gave indications of severe scale buildup within the scrubber* and demister, and severe solids buildup in the demister and on the underside of the Koch tray. Effluent residence times between 4.4 and 20 minutes could not be obtained during these tests due to system constraints (the larger effluent hold tank was used for the 20 minute tests and a smaller recirculation tank for the 4.4 minute tests).

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*The maximum sulfate supersaturation within the scrubber system occurs at the scrubber effluent. Hence, scale formation is heaviest on the bottommost grid of the TCA (see Section 6).

The acceptable effluent residence time, therefore, is between 4.4 and 20 minutes, at a percent solids recirculation of approximately 9 percent (with 40 percent of solids fly ash), a gas rate of approximately 8 ft/sec and a liquid-to-gas ratio of approximately 80 gal/mcf. Tests at the EPA TCA pilot facility at Research Triangle Park (which will be discussed in Section 6) have indicated that an effluent residence time of 10 minutes is satisfactory, for a liquid-to-gas ratio equal to or greater than 65 gal/mcf and a percent solids recirculated of 10 percent, provided that an appreciable amount of fly ash is present (40 percent of the solids are fly ash).

Marble-Bed System. The condition of the Marble-Bed scrubber at the termination of the reliability verification tests was poor (see Tables 3-3 and 3-6), because of problems associated with erosion of the CE bed nozzles, and the resultant insufficient wetting of the underneath of the marble-bed and subsequent pluggage of the bed. The use of hollow-cone Spraco nozzles also caused insufficient wetting of the bed and subsequent pluggage (see Runs 504-3A, 505-3A, and 506-3B). Future lime reliability verification tests will be conducted with the Marble-Bed scrubber with new, improved CE full-cone nozzles.

3.1.2 Analytical Data

A complete summary of scrubber inlet liquor analytical data for the limestone reliability verification tests is presented in Table 3-7. Except where noted, most of the dissolved species appear to have approached steady-state concentrations for these runs. The liquid analytical data are tested by inputting the measured compositions and pH's into a modified Radian Equilibrium Computer Program (Reference 4),

Table 3-7

AVERAGE SCRUBBER INLET LIQUOR COMPOSITIONS FOR LIMESTONE RELIABILITY VERIFICATION RUNS

Run No.	Percent Solids Recirculated	Effluent Residence Time, min.	Percent Solids Discharged	Percent Sulfur Oxidized	Scrubber Inlet pH Range	Inlet Liquor Species Concentrations, mg/l (ppm)									Calculated Degree of Saturation, %[d]	
						Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	$CaSO_3 \cdot 1/2H_2O$[e]	$CaSO_4 \cdot 2H_2O$[f]
Venturi																
501-1A	16	20	20-28	5-25	5.8-6.0	2000	220	50	-	200	1300	200	3000	7000	83	96
506-1A	8	12	55-65	20-35	5.4-5.7	4200[a]	480[a]	140[a]	85[a]	200	2100	40	7800[a]	15,000[a]	68	167
507-1A[b]	8	12	53-68	25-45	5.3-5.7	5100	510	140	180	120	2500	25	10,200	18,800	43	204
TCA																
501-2A	16	20	25-48	20-40	5.7-6.0	1800	300	50	-	100	1600	100	2600	6500	35	109
502-2A	16	20	31-39	17-35	5.8-6.1	1600	200	100	40	150	1250	250	2200	5800	61	87
509-2A	8	20	26-45	32-50	5.5-5.8	2700	350	100	70	220	1900	250	4800	10,400	73	138
510-2A	8	20	26-44	35-55	5.4-5.5	3000	400	100	70	180	2000	80	5000	10,800	47	149
514-2A	16	4.4	27-52	20-50	5.2-5.6	3000	350	100	80	190	2000	70	5000	10,800	46	152
515-2A	8	4.4	34-44	25-50	5.2-5.4	3300	310	120	120	210	2500	20	5800	12,400	46	193
Marble-Bed																
501-3A & 3B	11	30	20-29	15-35	5.8-6.0	2200	200	50	-	250	1500	100	3500	7800	105	113
502-3A	11	30	19-25	10-30	5.8-6.1	1500	120	50	-	200	1000	200	2200	5300	80	74
505-3A[c]	11	30	60-65	10-30	5.6-5.8	2800	300	150	50	200	1400	250	5500	10,600	74	106
506-3B	11	30	60-66	20-40	5.5-5.8	5000	450	150	120	200	1800	250	9400	17,400	88	150

(a) Concentration at end of run. Concentration increasing throughout run.

(b) Concentrations for first half of run are listed. Percent solids discharged was 20-30% during second half (using clarifier only) and total dissolved solids decreased gradually to 11,300 ppm.

(c) Only one liquor analysis taken.

(d) (activity Ca^{++}) x (activity anion) / (solubility product at 50 °C)

(e) Based on a solubility product for $CaSO_3 \cdot 1/2\ H_2O$ of 4.5×10^{-7}, which was fit to previous pilot plant data (C. Y. Wen, private communication, January 1973).

(f) Based on a solubility product for $CaSO_4 \cdot 2H_2O$ of 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process," NAPCA Report, June 9, 1970).

which then calculates the ionic imbalance. For the data shown in Table 3-7, the calculated ionic imbalances were all less than 13 percent.

The large concentrations of chloride ions are attributable to chlorides present in the coal which were converted to HCl and absorbed from the flue gas in the scrubber. A. Saleem (Reference 5) of Ontario Hydro has reported similar chloride concentrations during limestone wet-scrubbing tests with flue gas from a coal-fired boiler.

Venturi Runs 506-1A and 507-1A and Marble-Bed Runs 503-3A through 506-3B demonstrate the higher degree of closed-loop operation that is achieved by use of the clarifier and centrifuge, rather than the clarifier alone, to separate solids (53-68 percent solids discharged vs. 19-29 percent). Total concentration of dissolved species was more than doubled for these runs.

The calculated values for the degree of liquor saturation with $CaSO_3 \cdot 1/2\ H_2O$ and $CaSO_4 \cdot 2H_2O$ presented in Table 3-7 were made with the use of the modified Radian program. The calculated degrees of sulfate saturations for the scrubber effluent liquors (which have not been presented in this report) are, of course, greater than the predicted saturations for the scrubber inlet liquors (see Section 6). The calculated degrees of sulfite saturation are subject to large error, due to the uncertainty in the value of the solubility product and the large experimental error associated with measuring the sulfite concentrations. It is likely that, at steady state, with solid $CaSO_3 \cdot 1/2\ H_2O$ present, the liquid phase would be saturated with respect to sulfite.

The TCA data from Table 3-7 indicates an increase in the degree of sulfate supersaturation of the scrubber inlet liquor when effluent residence time is decreased from 20 minutes to 4.4 minutes (Run 515-2A vs. 509-2A and 510-2A) and when the percent solids recirculated is decreased from 16 to 8 percent at 4.4 minutes residence time (Run 515-2A vs. 514-2A). This result is consistent with the TCA reliability verification test results discussed in Section 3.1.1. Sulfate scaling of the bottommost TCA grid occurred when the effluent residence time was decreased from 20 minutes to 4.4 minutes, and increased in severity when the percent solids was decreased from 16 to 8 percent at 4.4 minutes (see Table 3-2). From the data in Tables 3-2 and 3-7, it would appear that sulfate scaling is likely to occur in the TCA scrubber for a degree of sulfate saturation of the scrubber inlet liquor greater than approximately 150 percent, at a liquid-to-gas ratio of 64 gal/mcf and a percent solids recirculated between 8 and 16 percent (40 percent of solids is fly ash).

A small amount of analytical data has been analyzed for the wash liquor to the spray tower and Marble-Bed demisters and the TCA Koch tray. The results have shown that the inlet wash liquors, which are composed of mixtures of clarified process liquor and available raw water makeup, have approximately 60 percent of the degree of sulfate saturation of the scrubber inlet liquor, at typical conditions. Even though the wash liquor may be less than saturated when introduced, SO_2 absorption and oxidation on the mist eliminator surfaces can cause supersaturation and scaling.

3.1.3 Material Balances

The results of material balances for calcium and sulfur for many of the limestone reliability verification runs, during continuous (uninterrupted) on-stream operating periods, are given in Table 3-8. The SO_2 absorbed was computed from the measured inlet gas rate, the inlet and outlet gas SO_2 concentrations and the estimated gas outlet rate. The calcium added was computed from the measured volumetric rate of limestone slurry additive and the solids concentration in the slurry. The sulfur and calcium discharged were computed from the measured rate of slurry discharged from the system and the concentrations of sulfur and calcium in the discharge.

The computed inlet and outlet rates for calcium and sulfur are in good agreement. The average stoichiometric ratios, based on solids analyses, are probably more accurate than the values based on limestone addition rate and SO_2 absorption, due to uncertainties in the measurement of limestone slurry feed rate. The ionic imbalances for the bleed stream solids analyses, from which the calcium and sulfur discharge rates were calculated, averaged less than +5 percent (more cations than anions).

The continuous operating periods were broken up into "computational periods" of from 8 to 48 hours, and material balances made for each computational period and the results summed. The computed inlet and outlet rates for calcium and sulfur did not necessarily balance during each computational period, due to the unsteady conditions which prevail at any point in time (e.g., changing percent solids) and the resultant

Table 3-8

SUMMARY OF MATERIAL BALANCES FOR SULFUR AND CALCIUM FROM LIMESTONE RELIABILITY VERIFICATION TESTS

Run No.	Material Balance Period, hours	Sulfur Balance			Calcium Balance			Average Stoichiometric Ratio, Moles Ca Added/Mole SO_2 Absorbed	
		SO_2 Absorbed, lb-moles/hr	SO_x in Solids Discharged, lb-moles/hr	Percent Error	Ca in L-S Feed, lb-moles/hr	Ca in Solids Discharged, lb-moles/hr	Percent Error	Based on Limestone Added and SO_2 Absorbed	Based on Solids Analysis
Venturi									
501-1A	605	4.3	4.5	- 5	7.1	7.8	- 9	1.67	1.73
502-1A	210	3.9	4.0	- 4	6.2	7.4	-13	1.59	1.82
TCA									
501-2A	150	4.7	4.3	+ 8	4.5	5.0	-11	0.95	1.15
502-2A	170	5.6	6.0	- 7	11.6	10.6	+ 9	2.07	1.77
509-2A	465	4.7	4.1	+14	4.9	5.7	-15	1.03	1.38
M-B									
501-3A	150	4.2	4.1	+ 3	4.5	5.2	-13	1.06	1.26
501-3B(a)	140	4.3	4.4	- 2	6.2	6.2	0	1.45	1.42
506-3B(b)	360	3.8	4.2	-10	6.8	7.4	- 8	1.78	1.77

(a) Because of turbid clarifier overflow, some of the solids in the clarifier feed is returned to the scrubber. The values for SO_x and Ca discharged have been corrected for solids returned and are net discharge from the system.

(b) The values for SO_x and Ca discharged have been corrected for solids in the centrate returned to the scrubber.

accumulation (or depletion) of the species within the system. However, over a longer period of time (>150 hours) the accumulation term becomes negligible as compared to the total input or output of species.

3.1.4 SO_2 Removal and Limestone Utilization

The results of the limestone short-term factorial tests (see References 1 and 2), showed that SO_2 removal is a strong function of liquor rate, inlet liquor pH and, of course, scrubber geometry (e.g., number of stages in the TCA). For the venturi, TCA and Marble-Bed scrubbers, SO_2 removal was not significantly affected by gas rate (gas velocity), while for the spray tower, SO_2 removal was slightly affected by gas rate (increasing SO_2 removal for increasing gas rate at constant liquor rate). SO_2 removal is also a weak function of SO_2 inlet concentration (higher removal for lower concentration) and scrubber temperature (higher removal for lower temperature).*

The results from the EPA TCA pilot facility at Research Triangle Park have shown that limestone utilization (100 x moles SO_2 absorbed/moles $CaCO_3$ added) is a strong function of limestone "reactivity" (i.e., average particle size) and scrubber inlet liquor pH (see Section 6).

For the limestone reliability verification tests (see Tables 3-1, 3-2, and 3-3) SO_2 removals from 67 to 82 percent, 77 to 88 percent and 65 to 77 percent were obtained with the venturi/spray tower, TCA and Marble-Bed scrubbers, respectively. Corresponding average limestone utilizations of approximately 68 percent, 77 percent and 67 percent were obtained for the three scrubber systems. Not included in the above averages are runs in which there was an apparent decrease in limestone reactivity (due to larger limestone average particle size) and in which the effect of "high-pH" was being investigated (Runs 502-2A and 502-3A).

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*A 10 percent change in inlet SO_2 concentration or a 10°F change in liquor temperature would correspond to about a one percent change in SO_2 removal.

An example of a decrease in limestone utilization and increase in SO_2 removal due to an increase in inlet liquor pH can be seen by comparing TCA Runs 501-2A and 502-2A (see Table 3-2). An increase in average scrubber inlet pH from 5.8* to 6.0 resulted in a decrease of utilization from approximately 80 to 60 percent and an increase in SO_2 removal from approximately 83 to 93 percent.

An example of changes in limetsone reactivity (and, hence, in limestone utilization), due to changes in the average size of the limestone particles (limestone "grindability"), can be seen in Runs 501-1A (Table 3-1), 502-2A (Table 3-2), and 502-3A (Table 3-3). In Section 6, the effect of limestone particle size on limestone reactivity is discussed.

3.2 LONG-TERM RELIABILITY LIMESTONE TESTING

3.2.1 TCA Run 525-2A

The objective of the long-term test is to operate continuously for four to six months. On October 24, 1973, a limestone long-term reliability test (Runs 525-2A) was begun on the TCA system. Based on the results of the reliability verification tests and the tests conducted at the EPA pilot facility in Research Triangle Park, the following conditions were chosen for the long-term test:

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*The pH data from the Shawnee facility were not considered reliable during the initial reliability verification runs.

Gas Rate, acfm @ 300°F	25,000
Gas Velocity, ft/sec	9.8
Liquor Rate, gpm	1200
L/G, gal/mcf	64
Percent Solids Recirculated	15
Effluent Residence Time, min.	10
Total Pressure Drop, in. H_2O	8.5
Percent SO_2 Removal (controlled)	80-85
Solids Disposal System	Clarifier

Three beds of spheres were used, with five inches of spheres/bed. The top bed used UOP supplied thermo-plastic-rubber (TPR) spheres and the bottom two beds UOP supplied high density polyethylene (HDPE) spheres. Also, the wire support grids in the scrubber were replaced by sturdier bar-grids for the long-term run. A summary of the operating data for Run 525-2A is as follows:

Average Percent Limestone Utilization	71
Inlet SO_2 Concentration, ppm	1600-4000
Scrubber Inlet pH Range	5.7-5.6
Scrubber Outlet pH Range	5.3-5.6
Percent Solids Discharged	42
Dissolved Solids, ppm	8000
Predicted Percent Sulfate Saturation	120

After approximately 500 hours of operation the run was terminated, due to (1) unusually heavy solids buildup on the underside of the Koch Flexitray and on the scrubber walls between the top stage and the Koch tray, and (2) scale and solids buildup on the bottom vanes of the demister. Also, numerous (over 200) half-spheres of the TPR spheres were found in the scrubber and slurry circulating system. Half-spheres of TPR were also found lodged in the TCA inlet slurry spray nozzles. It should be noted that the scrubber stages (and bottommost grid) were free of scale after the 500 hour operating period, as was expected. The HDPE spheres had lost from 8-14 percent of their original weight and the TPR spheres about 2.6 percent.

It is hypothesized that the soft solids accumulated below the Koch tray were due to the partial blockage of the TCA slurry inlet nozzles by the TPR half-spheres, which produced high pressure drops across the nozzles, resulting in excessive entrainment of fine slurry droplets. The partially blocked nozzles may have also contributed to a large degree to the mist eliminator pluggage, but excessive gas velocity is a contributing factor.

3.2.2 TCA Run 526-2A

On November 21, 1973, a new TCA limestone long-term reliability test (Run 526-2A) was begun. The TPR spheres in the top bed had been replaced with HDPE spheres*, and the accumulated scale and soft solids from Run 525-2A had been removed. The run conditions were identical to those for Run 525-2A, excepting that the gas velocity has been dropped to 8 ft/sec (20,500 acfm). The velocity was reduced because more detailed investigation of previous reliability verification runs indicated that long-term reliability for the present Koch tray/demister configuration should not be expected at a gas velocity of 9.8 ft/sec (compare Runs 509-2A and 510-2A in Tables 3-2 and 3-2). A summary of the operating data for Run 526-2A is as follows:

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*Once strainers are installed in the TCA system lines, it is planned to replace all three stages of spheres with TPR spheres.

Stoichiometric Ratio, moles Ca/mole SO_2 absorbed	1.3-1.6
Average Percent Limestone Utilization	70
Inlet SO_2 Concentration, ppm	1800-3400
Scrubber Inlet pH Range	5.6-5.9
Scrubber Outlet pH Range	5.2-5.5
Percent Solids Discharged	43
Dissolved Solids, ppm	8000
Predicted Percent Sulfate Saturation	120

On January 9, 1974, Run 526-2A was interrupted after 1190 hours of on-stream operation, in order to check the wear rate of the HDPE spheres in the three beds (HDPE sphere life had been estimated to be less the 2000 hours). Pressure drop across the chevron mist eliminator increased slightly during the initial 800 hours of operation, and during the last 400 hours increased more rapidly to a final level about 1.5 times the initial value of 0.18 inches H_2O.

A inspection was conducted on January 9, 1974, and the accumulation of sulfate scale and solids within the scrubber system is shown in Figure 3-1.

The general appearance of the scrubber was good. Scattered solids deposits (up to 1 inch) covered the walls of the scrubber below the bottommost bar-grid. Abour 1/16 inch thick scale was found on the walls below the bottommost grid and on the wall areas not in contact with the spheres. The 4 bar grids were covered with 10-14 mil scale.

Heavy solids deposit covered the inlet slurry spray nozzles and header and adjacent walls between the elevation of the nozzle tips and Koch wash tray. A heavy relatively uniform (about 1 inch thick) solids

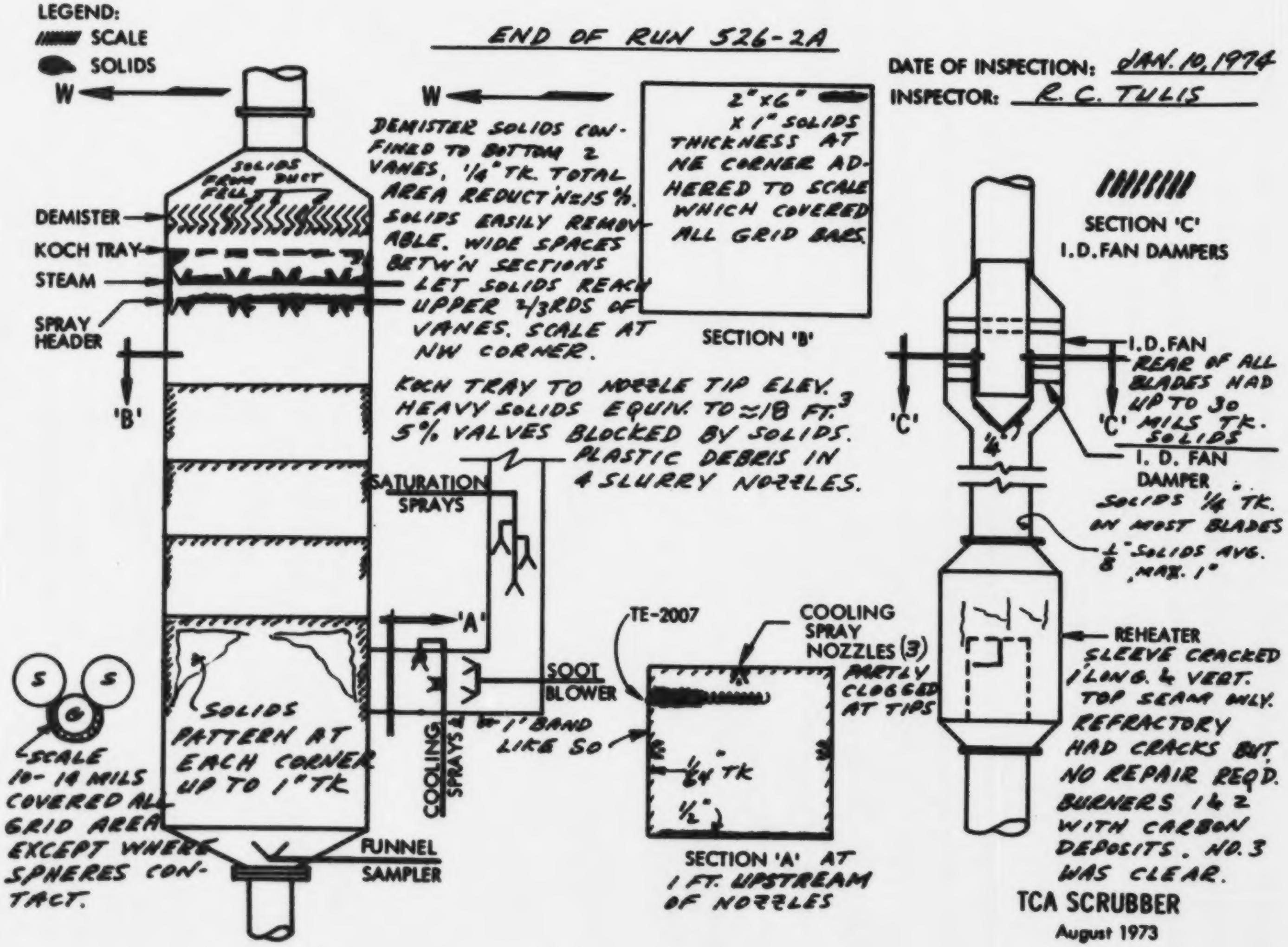
LEGEND:
SCALE
SOLIDS
W
END OF RUN 526-2A
DATE OF INSPECTION: JAN. 10, 1974
INSPECTOR: R. C. TULIS
SOLIDS FROM DUCT FELL
DEMISTER
KOCH TRAY
STEAM
SPRAY HEADER
'B'
W
DEMISTER SOLIDS CONFINED TO BOTTOM 2 VANES, 1/4" TK. TOTAL AREA REDUCT'N≈15%. SOLIDS EASILY REMOVABLE. WIDE SPACES BETW'N SECTIONS LET SOLIDS REACH UPPER 2/3RDS OF VANES. SCALE AT NW CORNER.
2"x6" x 1" SOLIDS THICKNESS AT NE CORNER ADHERED TO SCALE WHICH COVERED ALL GRID BARS.
SECTION 'B'
KOCH TRAY TO NOZZLE TIP ELEV. HEAVY SOLIDS EQUIV. TO ≈18 FT.³ 5% VALVES BLOCKED BY SOLIDS.
PLASTIC DEBRIS IN 4 SLURRY NOZZLES.
SATURATION SPRAYS
'A'
COOLING SPRAYS
SOOT BLOWER
1" BAND LIKE SO
FUNNEL SAMPLER
S
S
G
SCALE 10-14 MILS COVERED ALL GRID AREA EXCEPT WHERE SPHERES CONTACT.
SOLIDS PATTERN AT EACH CORNER UP TO 1" TK
TE-2007
COOLING SPRAY NOZZLES (3) PARTLY CLOGGED AT TIPS
1/64" TK
1/2"
SECTION 'A' AT 1 FT. UPSTREAM OF NOZZLES
SECTION 'C'
I.D. FAN DAMPERS
I.D. FAN
REAR OF ALL BLADES HAD UP TO 30 MILS TK. SOLIDS
'C'
'C'
1/4"
I. D. FAN DAMPER
SOLIDS 1/4" TK. ON MOST BLADES
1/8" SOLIDS AVG., MAX. 1"
REHEATER
SLEEVE CRACKED 1' LONG. & VERT. TOP SEAM ONLY. REFRACTORY HAD CRACKS BUT NO REPAIR REQ'D. BURNERS 1 & 2 WITH CARBON DEPOSITS. NO. 3 WAS CLEAR.
TCA SCRUBBER
August 1973

Figure 3-1. TCA Inspection

layer covered the underside of the wash tray. Approximately 5 percent of the tray valves were covered with solids. All four inlet slurry spray nozzles were partially plugged with debris, primarily with plastic covering from pipe insulation. Demister plugging was confined to the bottom two passes only (1/4 inches thick solids), reducing the free flow area by about 15 percent.

The flue gas outlet duct was covered with scattered (up to 1 inch thick) solids, with approximately 20 percent of the surface clean to metal. About 1/4 inch thick solids covered the underside (upstream) surfaces of the ID fan damper louvres. The downstream sides of the ID fan blades were covered with up to 30 mils of dry solids.

The average weight loss of the HDPE spheres from each bed was as follows:

	Hours in Use	Percent Weight Loss*
Top Bed	1190	28
Middle Bed	1707	40
Bottommost Bed	1707	23

As with Run 525-2A, it is hypothesized that the solids accumulations on the inlet slurry spray nozzles and header and on the underside of the Koch tray were primarily caused by partial blockage of the TCA slurry inlet nozzles by debris, which produced high pressure drops across the nozzles, resulting in excessive entrainment of fine slurry droplets. Also, the blocked nozzles may have been a major factor contributing to the mist eliminator pluggage observed, It should be noted that the accumulation of sulfate scale on the bottommost bar grid (10-14 mils) is not excessive, after the approximate 1700 hours of operation without cleaning. This is not surprising, since the scrubber inlet liquor was only 20 percent supersaturated with respect to sulfate.

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*Some of the discrepancy in the weight loss results between the middle and bottom beds could be attributed to the difference in sphere material quality in the beds. The HDPE spheres have been supplied by two different manufacturers.

3.3 PARTICULATE REMOVAL EFFICIENCIES

3.3.1 Equipment

For the overall particulate removal in the three scrubber systems during the limestone factorial testing, a modified EPA particulate train (manufactured by Aerotherm/Acurex Corporation) was used to measure mass loading at the scrubber inlets and outlets.

During the limestone reliability verification testing, a special series of tests using a Brink impactor were conducted by EPA to measure the TCA inlet and outlet aerodynamic size distributions. In order to utilize the Brink impactor at scrubber inlet mass loading conditions, a modified EPA particulate mass sampling train was used. The train is of 316 stainless steel construction and consists mainly of a heated sample probe (6 feet x 1/2 inch outside diameter), a cyclone, and the Brink impactor with a 144 mm glass fiber filter. The impactor draws a sample from the gas stream exiting the cyclone. Previous work had established that the particulates collected in the cyclone had a mass mean diameter of approximately 5 microns at a flow rate of one cubic foot per minute. At the scrubber outlet, the Brink impactor was used directly in the flue gas duct (without sample probe and cyclone).

3.3.2 Overall Removal Efficiencies

The overall particulate removal efficiencies for the three scrubbers obtained during the limestone short-term factorial testing (see Figure 2-4), are presented in Tables 3-9, 3-10, and 3-11. Only those data which were taken at close-to-isokinetic sampling conditions have been included in the tables. All of the outlet particulate data have been corrected for soot-contamination from the flue gas reheaters.[*] The soot amounted to less than 30 percent of the total mass of the outlet particulates.

From Table 3-9, it is seen that overall particulate removal efficiencies of 99.4 to 99.8 percent[**] were obtained for the Chemico venturi at a gas flow rate of 30,000 acfm (330°F) and liquid-to-gas ratios from 13 to 27 gal/mcf (300-600 gpm), with venturi plug pressure drops from 6 to 12 inches H_2O. For the spray tower, the removal efficiency was about 98.5 percent at a gas velocity of 4 ft/sec and a liquid-to-gas ratio of 40 gal/mcf (15,000 acfm and 450 gpm).

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[*] This problem of soot contamination from the oil-fired reheaters has been temporarily solved (see Section 4.4).

[**] For an average scrubber inlet grain loading of 3.5 grains/scf, a particulate removal of 99.0 percent would correspond to 0.07 lbs particulate discharged per 10^6 Btu.

Table 3-9

OVERALL PARTICULATE REMOVAL IN VENTURI AND SPRAY TOWER SCRUBBER DURING FACTORIAL TESTS

Run No.	Date	Gas Rate, acfm @ 330°F	Liquor Rate, gpm		Pressure Drop, in. H_2O		Grain Loading, grains/scf		Percent Removal
			Venturi	Spray Tower	Venturi	Spray Tower*	Inlet	Outlet	
415-1A	11-09-72	30,000	305	0	9.0	2.0	4.38	0.012	99.7
414-1D	11-12-72	30,000	305	0	9.0	1.9	2.1	0.010	99.5
414-1D	11-14-72	29,900	305	0	9.0	1.9	3.32	0.013	99.6
414-1C	11-15-72	29,900	305	0	6.4	1.9	3.40	0.02	99.4
417-1A	12-22-72	30,000	605	0	9.5	1.9	3.38	0.012	99.6
414-1E	12-25-72	30,000	300	0	12.0	1.9	4.17	0.009	99.8
418-1C	12-27-72	14,900	600	0	12.5	0.4	6.39	0.114	98.2
453-1B	12-31-72	14,900	12	460	2.5	0.45	2.6	0.004	99.8
454-1B	1-04-73	14,900	12	450	0.75	0.45	4.62	0.07	98.5
456-1A	1-05-73	14,900	12	450	0.70	0.45	3.38	0.056	98.3

*Including demister.

Table 3-10

OVERALL PARTICULATE REMOVAL IN TCA SCRUBBER WITH FIVE GRIDS AND NO SPHERES DURING FACTORIAL TESTS

Run No.	Date	Gas Rate, acfm @ 330°F	Liquor Rate, gpm	Total Pressure Drop, in. H_2O	Grain Loading, grains/scf		Percent Removal
					Inlet	Outlet	
WC-5	12-21-72	19,200	730	3.8	1.70	0.004	99.8
WC-5A	1-06-73	19,300	730	4.7*	4.16	0.029	99.3
WC-5A	1-09-73	19,300	730	5.5*	1.32	0.019	98.6
WC-11	1-12-73	19,400	745	7.0*	3.29	0.017	99.5
WC-12	1-14-73	19,300	375	7.1*	3.65	0.022	99.4

*High total pressure drop (including Koch tray, demister, and inlet duct) due to the pluggage of inlet gas duct by solids deposit.

Table 3-11

OVERALL PARTICULATE REMOVAL IN MARBLE-BED SCRUBBER DURING FACTORIAL TESTS

Run No.	Date	Gas Rate, acfm @ 330°F	Liquor Rate, gpm	Total Pressure Drop, in H_2O	Grain Loading, grains/scf		Percent Removal
					Inlet	Outlet	
427-3A	11-13-72	20, 000	810	12.2	2.6	0.030	98.8
427-3A	11-16-72	20, 000	810	12.2	3.32	0.035	98.9
426-3B	11-28-72	20, 000	810	10.2	4.43	0.032	99.3
427-3C	12-02-72	20, 000	800	12.7	4.24	0.033	99.2
427-3B	12-24-72	20, 000	805	11.2	2.19	0.027	98.8
428-3A	12-28-72	20, 000	810	11.7	3.78	0.025	99.3
428-3A	12-29-72	20, 000	810	11.7	4.12	0.016	99.6
428-3A	12-30-72	20, 000	810	11.7	3.63	0.035	99.0
438-3A	1-07-73	19, 900	400	7.2	4.20	0.020	99.5
440-3A	1-11-73	12, 500	600	6.9	3.82	0.042	98.9
440-3A	1-13-73	12, 500	600	6.9	3.59	0.066	98.2

Table 3-10 shows that, for the TCA scrubber with 5 grids and no spheres, the overall removal efficiencies were 98.6 to 99.8 percent at a gas velocity of 7.5 ft/sec and a liquid-to-gas ratio of 50 gal/mcf (19,300 acfm and 730 gpm), with total pressure drops (includes Koch tray, demister and inlet duct) of 4 to 7 inches H_2O.

The Marble-Bed scrubber (see Table 3-11) gave an overall particulate removal efficiency range of 98.8 to 99.6 percent, at a gas velocity of 5 ft/sec and a liquid-to-gas ratio of 54 gal/mcf (20,000 acfm and 810 gpm), with 12 inches H_2O total pressure drop.

During the limestone reliability verification testing, a series of particulate removal tests with the TCA scrubber (3 stages, 5 inches of spheres/stage) were conducted by EPA. Results from these tests are presented in Table 3-12. The overall removal efficiencies of 98.7 to 99.9 percent were achieved at gas velocities from 8 to 10 ft/sec (20,000-25,000 acfm), liquid-to-gas ratios from 40 to 80 gal/mcf (600-1200 gpm), and total pressure drops from 5.5 to 10 inches H_2O. The higher pressure drops generally gave higher overall removal efficiencies.

The overall particulate removal efficiencies shown in Tables 3-9 through 3-12 appear to be higher than the efficiencies predicted from the "impaction theory." These improved efficiencies could be due to (1) the condensation of water vapor in the flue gas on the solid particles* and (2) solids accumulations upon the demisters or underneath the TCA Koch tray during the duration of particulate testing. More testing is planned to provide a better definition of the mechanisms.

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*The condensation of water vapor per unit mass of inlet solids has been estimated to be from 1-5 grains water/grain inlet particulates within the scrubber.

Table 3-12

OVERALL PARTICULATE REMOVAL IN TCA SCRUBBER DURING LIMESTONE RELIABILITY VERIFICATION TESTS

Run No.	Date	Gas Rate, acfm @ 300°F	Liquor Rate, gpm	Pressure Drop, in. H_2O	Grain Loading, grains/scf		Percent Removal
					Inlet	Outlet	
503-2A	5/22-23	25,000	1200	9.8	3.16	0.00852	99.7
					3.00	0.00375	99.9
506-2A	5/24	20,000	1200	7.5	2.89	0.0143	99.5
					2.13	0.0152	99.3
505-2A	5/23	20,000	600	5.6	2.34	0.031	98.7
					2.61	0.020	99.2
					2.28	0.010	99.6

3.3.3 Particulate Size Distribution in the TCA

For the runs listed in Table 3-12, the particle size distributions of the particulates at the TCA inlet and outlet were also determined. The results are shown in Figure 3-2.

As shown in Figure 3-2, the mass mean diameter of the inlet solids is approximately 23 microns, which is slightly greater than the "normal" range of 10 to 20 microns. The data for the outlet size distribution shows some scatter. The mass mean diameter ranges from about 0.5 to 0.75 micron, for a total pressure drop range of 5.5-10.0 inches H_2O. Generally, the higher pressure drops give smaller outlet mass mean diameters.

3.3.4 Particulate Removal Efficiency in the TCA as a Function of Particle Size

The particulate removal efficiency as a function of particle size was determined by EPA for the TCA runs shown in Table 3-12. In Figure 3-3 the percent penetration (100-percent removal) is plotted vs. particle diameter in microns, for different ranges of total pressure drop.

From Figure 3-3, it is seen that for the submicron particles (0.11 to 0.99 micron), the removal efficiency drops rapidly with decreasing particle size, especially at low total pressure drop. The efficiencies were 95 to 99 percent at 9.8 inches H_2O total pressure drop, 93 to 95 percent at 7.6 inches H_2O, and 71 to 90 percent at 5.6 inches H_2O. Because of the limited number of tests, conclusions regarding submicron collection efficiency should be reserved until additional testing can be carried out.

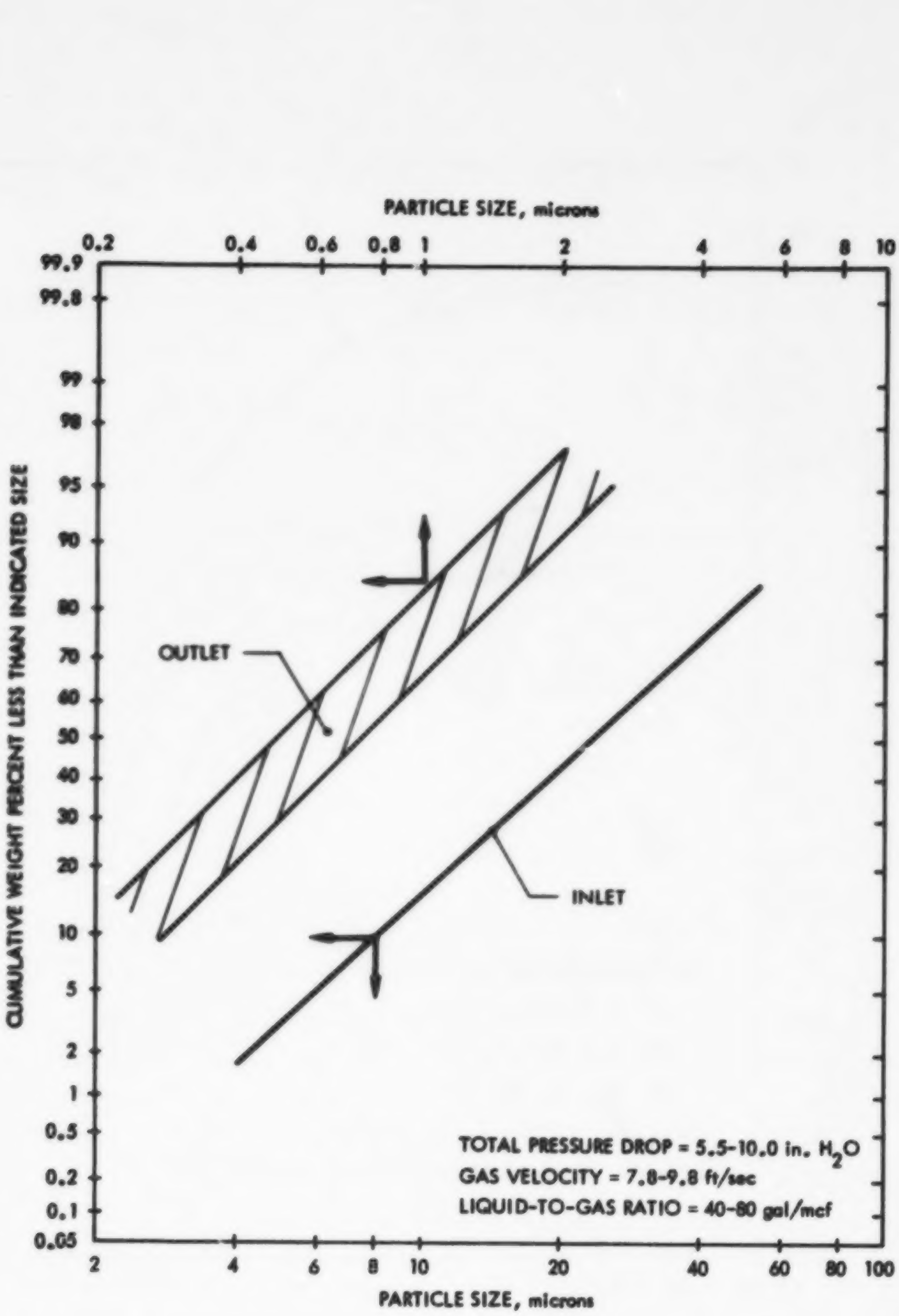

Figure 3-2. Particle Size Distributions at TCA Inlet and Outlet

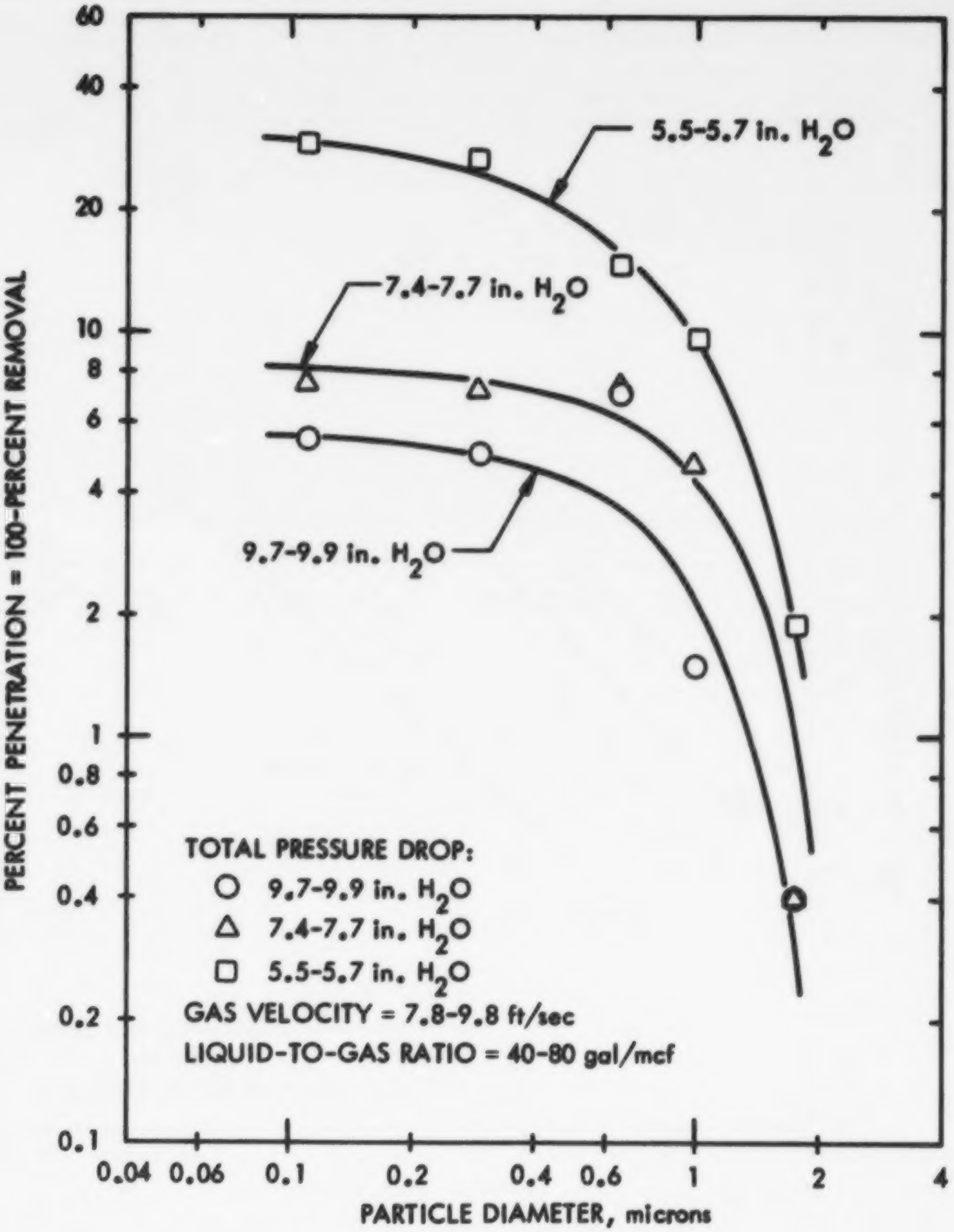

Figure 3-3. TCA Particulate Removal Efficiency as a Function of Particle Size

Section 4

OPERATING EXPERIENCE AT THE SHAWNEE FACILITY DURING LIMESTONE TESTING

In this section, the operating experience at the test facility during the open liquor loop short-term factorial testing and the closed liquor loop limestone reliability verification testing are summarized. The results of a material evaluation program are also summarized. Scaling and plugging tendencies on the scrubber internals have been discussed, primarily, in Section 3.

4.1 CLOSED LIQUOR LOOP OPERATION

For closed liquor loop operation, the raw water input to the system is equal to the water normally exiting the system in the humidified flue gas and the waste product. The original test facility design included slurry pumps with water seals (Hydroseals) for bearing protection, water quench sprays for gas cooling, water sprays for mist eliminator washing, a water wash for the Koch tray in the TCA scrubber, and dilute limestone slurry feed (10 - 20 wt % limestone). The water input under these conditions exceeded the makeup requirement for closed liquor loop operation. The systems operated, therefore, with partially open liquor loops during the limestone short-term factorial tests, i.e. process liquor had to be discharged from the systems, in order to maintain the overall water balances. This was not considered to be a serious problem during factorial testing for, at a specified scrubber inlet liquor pH, SO_2 removal is not significantly affected by liquor composition. However, little information was gained about the effect of scaling potential on reliability during this period.

The absorbent feed systems were changed in November 1972, to provide slurry feeds with up to 60 wt % limestone concentration. During the 5 week boiler outage in February and March 1973, the Hydroseal slurry pumps were converted to a Centriseal type (mechanical seal supplemented with air purge); quench spray systems using circulating slurry were provided for the TCA and Marble-Bed scrubbers; and, the Koch tray wash system on the TCA scrubber and the mist eliminator wash systems on the spray tower and the Marble-Bed scrubber were converted to use clarified liquor plus raw water makeup. Required revisions to bleed control, flow measurements and control instrumentation were also made during this period.

As a result of the modifications, closed liquor loop operation (based on discharge of thickener underflow) has been maintained at the facility since the beginning of limestone reliability verification testing in March 1973.

4.2 DEMISTERS

The specifications for the demisters tested on the three scrubber systems are given in Table 4-1. The demisters are depicted, to

Table 4-1

TEST FACILITY DEMISTER SPECIFICATIONS

	Spray Tower		TCA	Marble-Bed
Material of Construction	Stainless Steel	Polypropylene	Stainless Steel	Stainless Steel
Design[a]	Chevron, open	Chevron, open	Chevron, closed	Chevron, closed
Number of Vanes (Passes)	3	4	6	3
Total Depth of Demister	7-11/16 in.	10 in.	14 in.	7-1/8 in.
Center-to-Center Distance Between Vanes	3-9/16 in.	3 in.	1-1/8 in.	3 in.
Included Vane Angle	100°	110°	120°	80°

[a] Open-vanes not joined, closed-vanes joined.

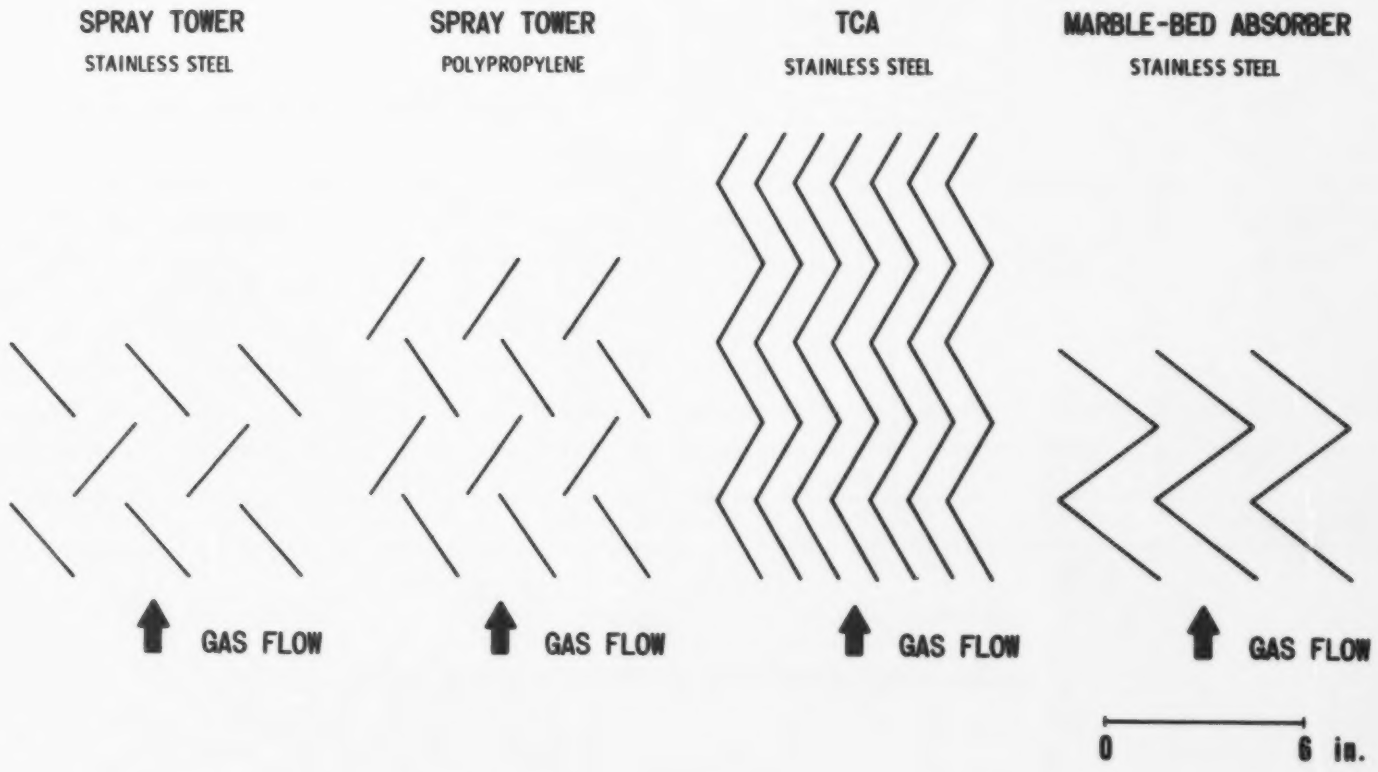
SPRAY TOWER
STAINLESS STEEL
SPRAY TOWER
POLYPROPYLENE
TCA
STAINLESS STEEL
MARBLE-BED ABSORBER
STAINLESS STEEL
GAS FLOW
GAS FLOW
GAS FLOW
GAS FLOW
0
6 in.

Figure 4-1. Test Facility Demister Configurations

scale, in Figure 4-1. The spray tower polypropylene chevron demister was used only during reliability verification Runs 502-1A, 503-1A and 506-1A (see Table 3-1).

In order to remedy demister solids accumulation problems encountered during the early stages of factorial testing, the following modifications were made to the systems:

(1) In November 1972, a Koch Flexitray wash tray was installed in the TCA scrubber between the inlet liquor spray header and the chevron demister, and a steam sparger was provided for cleaning the underside of the wash tray. At first, irrigation was obtained with raw water. A subsequent modification in February 1973 allowed for irrigation with process liquor, diluted with the available raw water makeup.

(2) During the boiler outage in early 1974 the spray tower and Marble-Bed demister systems were modified to allow for washing from both the upstream (underside) and downstream directions with process liquor, diluted with the available raw water makeup.

Wash-Tray Operation. The Koch Flexitray wash tray has been successful, to date, in significantly reducing the solids accumulation on the TCA demister blades at or below a scrubber superficial gas velocity of 8 ft/sec. However, heavy solids buildup did occur on the underside and below the Koch tray with intermittent steam sparging for one minute per 8 hour shift. Subsequent to the 5 week boiler outage, the steam sparging was increased to one minute per hour, which substantially reduced the solids accumulation below the tray. There was also an accumulation of solids underneath the Koch tray during a recent long-term reliability test (see Section 3.2 for a description of the problem).

Wash Liquor. During the limestone reliability verification tests on the three scrubber systems, the liquor wash to the demisters (and to the Koch tray) has varied from a ratio of about one part fresh water and six parts clarified liquor to half and half mixtures.* Occasionally, the undersides of the Marble-Bed and spray tower demisters have been washed intermittently, on a cycle that has averaged about 3 minutes "on" and 2 minutes "off", at an average rate of about 0.5-1 gpm/ft^2 during the spray cycle.

Polypropylene vs. Stainless Demister. The advantages of a polypropylene demister over a stainless steel demister are: (1) reportedly greater resistance to corrosion and erosion, (2) lighter weight, and (3) easier cleaning characteristics. These advantages are, however, largely offset by the plastic demister's poor impact resistance, which makes it more vulnerable to breakage during installation, operation, removal and cleaning. All of these characteristics were observed during venturi system Runs 502-1A through 506-1A (see Table 3-1).

Chevron vs. Centrifugal Demister. As part of the equipment evaluation program, both chevron and centrifugal (or whirl vane) demisters were tested in the venturi system after-scrubber. The pressure drop across the centrifugal demister was found to be prohibitive: about 5.0 and 7.0 inches H_2O at superficial gas velocities of 5.0 and 6.3 ft/sec, respectively. Apparently, the centrifugal unit supplied with the scrubber was not properly designed.

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*The mixture ratio is dependent upon the percent solids discharged, the percent solids recirculated and the gas flow rate.

Top (Downstream) Demister Wash. The results of venturi system Runs 506-1A, 507-1A and 508-1A showed that the use of top (downstream) demister wash resulted in a considerably reduced rate of solids buildup on the demister vanes. However, the carryover of slurry solids, which ultimately deposited on the reheater sleeve, the exhaust duct wall and the ID fan dampers, was substantial. It is believed that the abnormally high slurry droplet entrainment was primarily due to the short distance (14 inches) between the top wash nozzles and the top tangent of the spray tower and the resultant rapid acceleration of the gas as it approaches the converging outlet (96 to 40 inches diameter). The extent of solids deposition in the duct and on the fan dampers downstream of the reheater during runs with bottom wash only had been limited to light solids coatings.

Minimizing Demister Pluggage Problems. Based on the results to date at Shawnee, it appears that the following design provisions should be effective in minimizing plugging problems:

- Minimize scrubber superficial velocity, consistent with cost, turndown, space and other factors.
- Utilize a wash tray between the uppermost scrubber stage and demister.
- Wash demister from underside (downstream) with a mixture of clarified liquor and all available makeup water, and assure complete surface irrigation.

4.3 HOT GAS/LIQUID INTERFACE

The hot (~320°F) flue gas feed was humidified with raw water during the open-loop* factorial testing before entering the neoprene rubber lined TCA and Marble Bed scrubbers, to reduce its temperature below 190°F, the maximum permissible for liner protection. Cooling of the feed gas is not required in the venturi system, since the venturi scrubber itself is a very efficient humidifying device.

In spite of soot blowing with air** for 90 seconds (45 seconds in each direction of travel) at four hour intervals, there was a continual problem of soft solids buildup at the hot gas/liquid interface sections of the TCA and Marble-Bed scrubbers. There has been little evidence of any solids buildup within the venturi scrubber when the sootblowers have operated properly.

To facilitate closed-loop operation by minimizing raw water addition, the TCA and Marble-Bed scrubbers were provided with process slurry cooling systems during the boiler outage in February-March 1973.

The TCA system was equipped with a Ventri-Rod presaturator in the horizontal gas duct, two feet upstream of the scrubber entrance. The performance of the Ventri-Rod was not satisfactory in the horizontal flow configuration (rapid buildup of soft solids occurred both on and downstream of the Ventri-Rod) and it was replaced, during reliability verification Run 501-2A, with a humidification section consisting of four full cone Bete nozzles (ST-24 FCN).

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*See Section 4.1

**One blower per scrubber with two 3/4-inch diameter venturi nozzles leading and trailing at 15° from the vertical at a rated air consumption of 1920 scfm and a blowing pressure of 160 psig.

By subsequent careful selection of the proper size, orientation, location, and number of the spray nozzles, modification of the soot blower head (both nozzles leading at 45°), air blowing during forward travel only, and installation of a Y strainer in the process slurry line to the cooling spray nozzles, the buildup of solids in the inlet duct was eliminated.* These improvements resulted in the wet-dry interface being moved to within 12 inches of the scrubber entrance, from where accumulated solids are easily blown into the scrubber and discharged through the 36 inch downcomer for reslurrying in the effluent hold tank.

On the Marble-Bed scrubber, the modifications of the cooling slurry system resulted in moderate but encouraging results. The effectiveness of the latest modifications will be verified following the resumption of testing on the Marble-Bed system.

4.4 REHEATERS

Flue gas is reheated after evolving from the scrubber to prevent condensation and corrosion in the exhaust system, to facilitate isokinetic and analytical sampling, to protect the induced draft fans from solid deposits and droplet erosion, and to increase plume buoyancy. The reheaters originally employed were fuel oil fired units with separate combustion air supply and with combustion occurring in the flue gas stream. The reheaters had been difficult to start and operate during the short-term factorial testing and combustion had been incomplete, which led to a visible plume containing significant quantities of soot. This made it difficult to interpret outlet particulate data and affected gas sampling by the duPont SO_2 photometric analyzers. Moreover, significant quantities of oil-soaked soot accumulated in the duct work and, on two occasions, resulted in fires. The difficulty appeared to result from quenching of the flame by the cold (128°F) flue gas before complete combustion could occur, and from operating with the same fuel nozzles over a wide range of flow rates.

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*Excepting for Run 514-2A (see Section 3.1)

The reheater systems were modified during the scheduled boiler outage in early 1973. Internal stainless steel sleeves (10 gage, 304 SS, 40 inches in diameter by 4 feet high) were installed to provide approximately 50 cubic feet of isolated combustion zone for each reheater. Also, the turbulent mixing type nozzles supplied originally were replaced with mechanical atomizing nozzles. These new nozzles are designed for a relatively narrow range of oil flow rate and have to be changed when the reheat requirements change significantly. Nozzle replacement, however, is a simple job.

The above modifications appear to have been effective. Little or no soot is visible in the stack gas, and the outlet particulate samples have shown no appreciable quantities of carbon from the reheaters. Therefore, plans for installation of an external combustion system on one of the reheaters have been deferred.

To assess their durability, the internal stainless steel sleeves were inspected periodically. On all three reheaters, sleeve failure in the form of warping, girth weld failure and excessive oxidation of the metal in the proximity of the burners occurred after 2000 to 3000 hours of operation. The warpage of the sleeves is attributed to unequal thermal stresses while operating with only two of the three burners and the excessive metal oxidation is caused by localized hot spots in the areas of flame inpingement. All three sleeves were replaced during July (Marble-Bed) and September 1973 (spray tower and TCA) with 1/4 inch thick 310 stainless steel ones of the original dimensions.

In September 1973, both the venturi and TCA reheaters were relined in preparation for the long-term test runs.

The modifications performed at the test facility are acceptable as an expedience for operation. However, operation is still not consistent with the requirements for long-term sustained reliability. Therefore, full scale application of direct-fired reheat, in applications where the flame is subject to quenching, is to be avoided.

4.5 FANS

Initially, considerable difficulty was experienced with the induced draft fans. Some of the problems included high fan vibration, fan motor failure, fan damper control failure and fan blade deformation. All of the problems, except for blade deformation, necessitated repeated shutdowns of the affected scrubber systems.

The unacceptable high vibration problem of all three fans was greatly reduced in June 1972, by insulating the fan housing, adding additional bracing to the outboard pedestals, and welding balance weights on the fan shrouds. However, occasional high fan vibration continued to hinder scrubber operation, particularly on the venturi system, and required either addition of shims to the bearings or replacement of the bearings (the high venturi fan vibration was due to excessive clearance between the outer bearing race and the bearing housing on the inboard bearing).

The motors of the venturi and TCA fans had to be returned once to the supplier for repair and correction of serious manufacturing problems.

Stable flue gas flow control was achieved by increasing the "fully open" to "full closed" fan damper response time from 10 to 100 seconds with new actuators. Three scrubber system shutdowns were caused by inoperable linkage and a broken shear pin.

Distortions of several blades (arc shapes as contrasted to the original straight line configuration) of the Marble-Bed and TCA fans were observed in March 1973. The maximum deformation was 0.55 inch on a blade of the Marble-Bed fan. The manufacturer indicated that the deformation was probably caused by stress relieving during fan operation and that the warping of the blades did not interfere with efficient, safe operation. No significant continuing deformation of the blades has been observed to date.

Erosion, corrosion, pitting, scaling, etc. to date have been negligible on all three fans. However, past operation has been only with 125°F flue gas reheat to give a fan outlet temperature of 250°F. Future plans include operation with only 50°F reheat.

4.6 PUMPS

Most of the pumps used at the Shawnee test facility in alkali slurry service are rubber lined variable speed centrifugal pumps. Most of the original Hydroseal type pumps were converted to either Centriseal type or were modified to include a mechanical seal during the boiler outage during February 1973.

Both the Hydroseal and Centriseal pumps have performed satisfactorily. It was necessary, however, to install pump discharge-to-suction recirculation lines to eliminate the vapor-lock problem of Centriseal pumps at low flow rates. More frequent replacement of packing material and shaft sleeves has also been noted in the Centriseal pumps.

In general, the rubber linings have been found to be in excellent condition. Part of one slurry spray nozzle was found in the effluent hold tank recirculation pump on the Marble Bed Scrubber, and had damaged the rubber lining. Wear rates of the rubber linings will be determined during the long-term reliability runs.

One stainless steel variable speed centrifugal pump was originally used in the limestone addition system. Severe erosion of the housing and impeller were noted (with a corresponding loss of 20% pumping efficiency) in only twenty days of actual operation. Subsequently, this pump was replaced by individual Moyno pumps to each scrubber system. Operation of the Moyno pumps (stainless steel rotor and butyl rubber stator) has been satisfactory with normal maintenance required. Wear rates will be determined during the test program.

4.7 WASTE SOLIDS HANDLING

The test facility is equipped to study alternate methods of waste solids dewatering and disposal. Separate clarifiers are provided for each scrubber system, and a rotary drum vacuum filter, a horizontal solid bowl centrifuge and a slurry settling pond are common to the three systems. Solids separation for any scrubber system can be achieved with any combination of clarifier/filter/pond or clarifier/centrifuge/pond.

4.7.1 Clarifiers

The clarifiers are conventional solids contact units with a heavy duty rake and scraper mechanism supported from a bridge. The vessels are flake-glass lined with a stainless steel rotating mechanism. The venturi and Marble-Bed systems have 20-foot diameter units while the TCA clarifier is 30 feet in diameter.

The performance of the clarifiers during the short-term factorial test period was unsatisfactory. Solids carryover in the overflow of the two smaller units was a problem and the solids concentration in the underflow streams of all three units could not be controlled.

Following extensive system modifications during the February 1973 power outage, so that a purge stream could be routed from each scrubber slurry recirculation loop directly to the clarifiers, the performance of the clarifiers improved significantly. The concentration of solids in the underflow of the larger TCA unit approaches the expected final settled density of the sludge (approximately 40 percent by weight). However, the poor settling characteristics of certain solids components, particularly calcium sulfite and fine fly ash, and the high solids loading in the bleed continued to result in periodic high solids carryover in the overflow of the 20 foot diameter venturi and Marble-Bed units (about 0.2 to 5.0 percent by weight at 14.5 to 25.0 tons per day solids loading, respectively). Also, the highest solids concentration in the underflow streams from these smaller units averaged about 25 percent by weight.

Preliminary test data with lime slurries indicate that, with the reduced solids loading to the venturi clarifier (due to better lime utilization), the solids concentration in the overflow averaged less than 0.1 percent by weight. The solids level in the underflow stream remained unchanged at about 25 percent by weight.

4.7.2 Centrifuge

Following some exploratory tests in April 1973, the centrifuge was used for solids dewatering in the venturi and Marble-Bed systems, directly or in series with a clarifier. The average feed rates were 25 to 35 gpm with solids concentration varying between 8 to 20 percent by weight. The operation of the centrifuge was quite satisfactory at 1 - 1/4 inch pool depth and 2000 RPM speed. The cake solids were in the 56 to 62 weight percent range and the centrate solids averaged 0.5 to 1.0 weight percent.

The centrifuge failed after about 1400 hours of operation. Detailed inspection revealed "above average" wear of the bowl and conveyor, requiring their return to the factory for repair. The eroded casing was repaired on site.

4.7.3 Filter

Following modifications to the system to facilitate trouble free discharge of the cake-wash water mixture, the rotary vacuum filter was operated continuously for about 200 hours. The cake discharge from the nylon cloth was satisfactory without the use of mechanical equipment (scraper or wire). Tests have indicated that the dewatering capability of the filter corresponds to 50-55 and 45-50 weight percent solids in the cake from limestone and lime slurries, respectively.

Filter operation has been significantly affected by the life of the filter cloth. The useful life of the polypropylene and nylon filter cloths tested to-date is unsatisfactory.

4.8 SCRUBBER INTERNALS

4.8.1 TCA Wire Grids

The original wire mesh grids (0.148 inch diameter stainless steel wires) deteriorated considerably during the approximately 3000 hours of operation in slurry service. Vibration caused by plastic sphere activity resulted in the rubbing together of the grid wires at their perpendicular junctions and the grids failed at several locations due to subsequent erosion of the wires in slurry service.

The wire mesh grids were replaced with sturdier "rod grids" (3/8 inch in diameter, SS rods, 1 - 1/4 inch on centers) prior to the long-term limestone reliability run.

4.8.2 TCA Spheres

A significant limiting factor in the long-term reliability of the TCA scrubber has been associated with the erosion and subsequent collapse of the UOP supplied 1 - 1/2 inch polypropylene and polyethylene plastic spheres used as packing. The collapsed spheres eventually fill with slurry and settle to the bottom of the support grid. Random samples of collapsed spheres, subsequent to the termination of the limestone factorial runs, showed about 60 percent weight loss. Other data has indicated a weight loss of about 27 percent for the plastic spheres, after approximately 1000 hours of operation.

During the initial phase of the long-term reliability limestone run on the TCA (see Section 3.2), the top-most bed utilized UOP supplied thermo-plastic-rubber (TPR) spheres, and the bottom two beds UOP supplied high density polyethylene (HDPE) spheres. After 500 hours of operation, the TPR spheres had lost approximately 2.6 percent of their original weight and the HDPE spheres from 8-14 percent. Also, about one percent of the TPR spheres in the top stage had come apart at the seams. Some of these half-spheres eventually lodged in the slurry recirculating nozzles, causing premature termination of the run.

4.8.3 Nozzles

Nozzle reliability at the test facility has been greatly reduced by the frequent plugging of spray nozzles with foreign material (TCA spheres, marbles, debris, etc.), and the erosion of some spray nozzles by the abrasive solids in the circulating slurries. It has become apparent that nozzle plugging could be reduced substantially by placing screens over open vessels in the scrubber systems and/or within the circulating slurry lines.

Spray Tower. Limestone factorial testing in the spray tower started with the use of spiral tip, 316 SS, full cone, Bete No. ST-24 FCN nozzles (capacity: 12 gpm @ 12 psig) manufactured by Bete Fog Nozzles, Inc. Because of frequent plugging with slurry and/or debris, these nozzles were replaced in September 1972, with Bete No. ST-32 FCN nozzles (capacity: 21 gpm @ 10 psig). Plugging of the larger Bete nozzles became less frequent. Neither type of nozzle showed any significant sign of erosion.

To allow for increased liquor flow to the four-header spray tower, Bete No. ST-48 FCN stainless steel nozzles (capacity: 47 gpm @ 10 psig) were installed during the February 1973 shutdown. During the first limestone reliability verification test (Run 501-1A), five of the 28 nozzles became totally plugged with debris and four nozzles became partially plugged. Although erosion of these stainless steel nozzles has not been observed to date, after approximately 3500 hours of slurry service, they will be replaced with identical stellite-tipped ST-48 FCN nozzles in the near future.

TCA. The large Spraco 1969, full cone, 316 SS, open-type slurry feed nozzles have performed satisfactorily and without significant erosion since the original startup of the unit. Occasional partial pluggage by large debris did not necessitate premature termination of any test run (excepting pluggage by TPR spheres, see Section 3.2).

Marble-Bed. The 22 original slurry feed spray nozzles lined with Solathane 291 and equipped with internal Adiprine LD 315 swirl vanes failed in various ways during short-term factorial testing. The swirl vanes in all 22 nozzles eroded, the liners of four bottom nozzles collapsed, and two bottom nozzles disintegrated. The nozzles frequently became plugged with slurry and debris.

The original slurry feed nozzles were replaced (during the February 1973 shutdown) with improved nozzles supplied by Combustion Engineering (stronger, Adiprine LD 3056 lining with improved bonding using Thixon 1244 between the liner and the body of the nozzle and a locking groove to hold the vanes in place). The diffusion vanes of 13 (of the 16) bottom spray nozzles failed during the initial limestone reliability verification test run (Run 501-3A), after 764 hours of operation.

4.9 LININGS

Two types of lining material were used throughout the scrubber systems. The Marble-Bed and TCA scrubbers, the venturi scrubber downstream of the plug, the venturi after-scrubber, the process water tanks, the pumps, the circulating slurry piping and the tank agitator blades are rubber lined. The effluent hold tanks and clarifiers are lined with Flakeline glass.

The rubber linings have been found, generally, to be in excellent condition. Essentially no erosion or deterioration has been noted. However, slight wear has been noted on some of the rubber-coated agitator blades. This type of wear is believed to be caused primarily by foreign objects striking the agitator blades (rubber lined pumps are discussed in Section 4.6).

Hairline cracks have been noted in the Flakeline lining of the effluent hold tanks and clarifiers. The cracks did not appear to penetrate the entire thickness of the lining. The cracks are more prevalent at the junction between the baffles and the tank walls. Isolated areas on the bottom of the TCA effluent hold tank also show wear by erosion. These areas are also near the wall baffles where eddy currents are formed.

Flakeline patching material is available for lining repair but has not been used to date. The eroded areas on the bottom of the TCA effluent hold tank were painted with epoxy.

Prior to starting the long term reliability run with limestone on the TCA, the agitator in the effluent hold tank was lowered four feet. As a precautionary measure, a steel wear plate was also installed on the bottom of the effluent hold tank covering the area under the agitator.

4.10 INSTRUMENT OPERATING EXPERIENCE

4.10.1 Sulfur Dioxide Analyzers

Essentially trouble-free operation was experienced with the duPont Model 400 UV sulfur dioxide analyzers following the modification of the sampling system and the replacement of interference filters in November 1972. Initially, the sampling system was particularly vulnerable to condensation, solid particulates, oil, soot, corrosion, or the combinations of these factors which led to leakage or plugging of the sampling lines, plugging of the filters, or coating of the optical lens. All of these effects caused erroneous sulfur dioxide analyzer readings.

To eliminate the problem areas, the sampling handling system was modified as follows:

- All heat sinks and sharp bends in the sample lines were eliminated. A new 3/8 inch diameter Dekeron sample line was installed to replace the original 1/4 inch stainless steel line. Heat tracing was installed along the full length of the sample line.
- Stainless steel shields furnished by duPont were installed around the probe filters. The original ceramic probe filters were replaced by probe filters made from 316 stainless steel and recently developed by duPont.
- An automatic zero and air blow-back system was installed on the SO_2 analyzers in the inlet gas ducts, similar to those provided originally in the scrubbed gas ducts.
- Stainless steel lines and fittings were replaced with Dekeron or Teflon plastic wherever possible.

- Calibration methods were changed to use a stainless steel wire mesh reference filter rather than bottled standard reference gas.

One additional problem associated with all six analyzers was the deterioration of the interference filter in the optic section. All of these filters, which filter out all except the desired light wave lengths, were replaced. The failure and subsequent deterioration of the filter was attributed by duPont to the exposure of the analyzers to freezing conditions prior to their installation. It was theorized by duPont that the freezing caused minute cracks which then deteriorated with time.

4.10.2 pH Meters

Operating experience has been gained with two types of pH meters. These are Uniloc Model 320 in-line flow-through type and Uniloc Model 321 submersible type pH meters.

The performance of the in-line flow-through type pH meters has been unsatisfactory due to the erosion of the glass cells by the slurry, their high rate of failure, and the frequent plugging of the sample lines. All the flow-through type meters at the scrubber inlet and outlet have subsequently been replaced by the submersible type meters.

For the submersible type pH meters, cell erosion, cell breakage, and sample line pluggage have not been experienced during the approximately 1300 on-stream hours of operation. Routine cleaning and calibration of the cells measuring the slurry pH at the scrubber inlet are made twice a week to maintain the desired meter accuracy with ± 0.1 pH unit. However, routine calibration checks during the scrubber operation have not been possible for the submersible cells located at the scrubber outlets (inside the downcomers). Studies are being made to effect the routine calibrations of the scrubber outlet pH meters during the operation of the scrubber systems.

4.10.3 Density Meters

Operating experience has been obtained with the Ohmart radiation-type, the bubble-type (differential pressure), and the Dynatrol Model CL-10HY U-tube type density meters.

Experience with the radiation-type density meter indicates a loss of calibration in the range of about 1 to 2 percent per week. Also, the meter accuracy is affected by the accumulation of scale in the sample line which can be removed only during the scrubber shutdowns.

The sample line and the probes of the bubble-type density meter plug frequently and require significant maintenance. However, the meter is accurate when clean and can be used to check the calibration of the Ohmart radiation-type density meters.

The Dynatrol density cells (using the vibration principle of the U-tube for continuous response to density changes) have been installed in September 1973, to measure the densities of the lime slurry feed to the venturi/spray tower system and of the circulating limestone slurry to the TCA system. The performance of this type of density meters has thus far been encouraging.

All three types of meters require further study and modification to achieve adequate reliability in their respective control service.

4.10.4 Flowmeters

Foxboro magnetic type and differential pressure type (both orifice and annubar) flowmeters are used at the test facility.

Operating experience with the magnetic flowmeters has generally been good. The main problem has been in obtaining accurate flow measurements at very low flow rates with meters designed to measure flow over a wide range. To assure accuracy, Foxboro recommended a minimum linear velocity of 3 ft/sec through the flow element.

The magnetic flowmeters smaller than 4 inches have a tendency to drift in calibration and frequent flow checks are required to verify the accuracy. Meters larger than 4 inches are more reliable; however, scale accumulations on the electrodes over an extended period influence the accuracy and necessitate periodic cleaning.

The Scothane liners in the magnetic flowmeters are vulnerable to failures attributable to leaving the power on for long periods during shutdowns when the meters are drained of liquid.

The orifice type flowmeters appear to function reasonably well in slurry service (6 to 15 percent solids by weight), provided that the problem of the plugging of pressure taps is resolved by using diaphragms as close as possible to the slurry piping. Preliminary inspection results indicate relatively little erosion of the 316 stainless steel orifice plates after about 2500 hours of operation.

Experience at the test facility indicates that annubar meters should be used only in non-scaling, clear liquid service (containing a maximem of 0.5 percent by weight of suspended solids) to prevent frequent plugging and associated maintenance work.

4.10.5 Control Valves

Operating experience with control valves in slurry service has generally been unsatisfactory. Severe erosion in a short time has been caused by the increasing velocity during throttling operation. This deterioration has been observed in the stainless steel plug valves, globe valves and rubber pinch valves. Satisfactory and trouble free flow control has been experienced only with variable speed pumps.

4.11 MATERIALS EVALUATION

TVA has conducted a study for the evaluation of corrosion and wear of plant equipment and test specimens (coupons) at the Shawnee facility. A detailed interim report of the results of this study, by G. L. Crow and H. R. Horsman, is presented in Appendix D. The following is a summary of some of the results of that study. Linings have been previously discussed in Section 4.9.

4.11.1 System Components

A thorough inspection of all system components was conducted during the extended February and March 1973, boiler outage. Each of the three scrubber systems had been operated for about 1800 hours during the factorial limestone scrubbing tests.

Localized deposits of loose fly ash accumulated in the mild steel gas ducts between the boiler and scrubber structure. The surfaces were coated with a thin iron oxide scale and moderate pitting had occurred at the uninsulated connections. The flanges and access doors have been insulated.

The most severe corrosion was found on Type 316 stainless steel surfaces, particularly on the mist eliminator blades in the TCA system. In general, the corrosion was in the form of pitting with some pits as large as 1/16-inch diameter and 30 to 35 mils deep.

Significant erosion was noted on the pump sleeves, at the intersections of the wire of support grids in the TCA scrubber, and on the impeller and casing of the 316 SS Gould limestone slurry pump.

4.11.2 Test Coupons

Test coupons of several different materials of construction, together with stressed and welded specimens, were exposed for periods of 1700 hours or longer to various slurry and gas environments. The corrosion rates observed are presented in Table 4-2.

Corrosion of Hastelloy C-276 was from negligible to 5 mils per year. This alloy showed no evidence of localized attack in any test location. Next in resistance to corrosion were Inconel 625, Incoloy 825, Carpenter 20 Cb-3, and Type 316L stainless steel alloys. The corrosion rates for each material ranged from negligible to 5, 7, 14 and 15 mils per year, respectively. These alloys had few minute corrosion pits and/or crevice corrosion. Type 316L, the fifth alloy in corrosion resistance, is the least expensive of this group of materials.

Three nonferrous alloys, Cupro-Nickel 70-30, Monel 400, and Hastelloy B, each had minimum corrosion rates of less than 1 mil. Maximum corrosion rates were 49, 57 and 100 mils per year, respectively. Only one or two specimens pitted. In three tests of Monel and in one test of Cupro-Nickel 70-30, the welds were inferior to the parent metal.

Table 4-2

CORROSION TEST RESULTS

Metals (a)	Corrosion, mils/yr	Number of Pitted Samples(b)	Pitted Depth, (c) mils		Number of Samples With Crevice Attack	Other Types of Attack	
			Min.	Max.		Number of Samples(b)	Area of Attack
1. Hastelloy C-276	Neg. to 5	-	-	-	-	-	-
2. Iconel 625	Neg. to 5	1	-	Minute	-	-	-
3. Incoloy 825	Neg. to 7	-	-	-	1	-	-
4. Carpenter 20Cb-3	Neg. to 14	2	-	Minute	-	-	-
5. Type 316L SS	Neg. to 15	3	-	Minute	2	1, 1	G18(d), Weld
6. Cupro-Nickel 70-30	>1 to 49	1	-	18	-	1	Weld
7. Monel 400	>1 to 57	1	-	2	1	3	Weld
8. Hastelloy B	>1 to 100	2	-	Minute	-	-	-
9. Type 446 SS	Neg. to <140	9	Minute	19	11	-	-
10. E-Brite 26-1	Neg. to <190	10	Minute	18	2	-	-
11. Incoloy 800	Neg. to <190	6	Minute	19	3	1	(e)
12. USS 18-18-2	Neg. to <200	11	Minute	16	11	-	-
13. Type 304L SS	Neg. to <200	14	Minute	25	11	1	(e)
14. Type 410 SS	>1 to <250	15	Minute	16	16	-	-
15. Aluminum 3003	>1 to <500	9	2	70	5	-	-
16. Mild Steel A-283	>1 to <1400	2	-	Minute	2	-	-
17. Cor-Ten B	>1 to <1400	5	Minute	5	4	1	Weld

Non-Metals(f)		Evaluation, Number of Samples		
		Good	Fair	Poor
Plastics	Bondstrand 4000	12	-	9
	Flakeline 200	2	14	5
	Qua-Corr	5	-	1
Rubbers	Butyl 1375	6	-	-
	Natural 9150	6	-	-
	Neoprene 26,666	6	-	-
Ceramic	Transite	14	2	5

Note: Test samples of each material were tested for 1680 hours, or more.

(a) Metals are listed in approximate order of decreasing corrosion resistance.

(b) Samples of each metal were tested in 21 locations.

(c) Depth of penetration in mils during total exposure period.

(d) Groove in parent metal is 18 mils deep.

(e) Severe localized attack of parent metal.

(f) Samples of Bondstrand, Flakeline and Transite were tested in 21 locations. Samples of Qua-Corr and rubbers were tested in 6 locations.

The corrosion rates of Type 446 stainless steel, E-Brite 26-1, Incoloy 800, USS 18-18-2, and Type 304L stainless steel, ranged from negligible to values which indicated that the alloy specimen was completely destroyed at one or more test locations. The values for the specimen failures ranged from greater than 140 mils per year for Type 446 to greater than 200 mils for both USS 18-18-2 and Type 304L stainless steels. These five alloys were highly susceptible to localized corrosion.

Another group of alloys, Type 410 stainless steel, 3003 aluminum, A-283 mild steel, and Cor-Ten B, had minimum corrosion rates of less than 1 mil per year and maximum corrosion rates of greater than 250 mils for Type 410 to greater than 1400 mils for A-283 and Cor-Ten B. Pitting and crevice corrosion occurred on the four alloys.

In general, the stressed specimens (five alloys only) were not corroded at rates higher than their counterpart disk-type specimens.

Specimens of Bondstrand 4000, Flakeline 200, and Transite materials were tested at 21 locations. Bondstrand 4000 showed good corrosion resistance in 12 tests and poor resistance in nine tests. Only six specimens of each of the following materials were tested: Qua-Corr plastic, butyl natural rubber and neoprene rubber. The results were: five good specimens and one poor specimen for Qua-Corr plastic, and six good specimens for each type rubber.

With few exceptions, mainly in the TCA system, the greatest loss of weight from metal specimens occurred in areas where the velocity of the unscrubbed, partially humidified flue gas was comparatively high. Impingement on the specimens of the slurry caused erosion and corrosion. Pitting and crevice corrosion were not important factors where erosion and corrosion kept the specimens clean. In other areas of the three scrubber systems where solids accumulated, the frequency of localized corrosion was high. However, each of the 17 alloys tested showed good corrosion resistance at one or more test locations in each scrubber system.

Section 5

LIME TEST RESULTS AT THE SHAWNEE FACILITY

On October 9, 1973, a reliability verification test run (Run 601-1A) was begun on the venturi/spray tower system. The primary variable selected for control was the pH of the recirculating (scrubber inlet) slurry. This value was automatically controlled at 8.0 ± 0.3 by coupling the pH meter to the lime addition system. This pH control level was chosen based upon the results of lime testing at the EPA pilot facility in Research Triangle Park (see Section 6), which indicated reasonable lime utilization (100x moles SO_2 absorbed/mole $Ca(OH)_2$ added) and SO_2 removal at that level. Other operating conditions were selected based on results from limestone reliability verification testing.

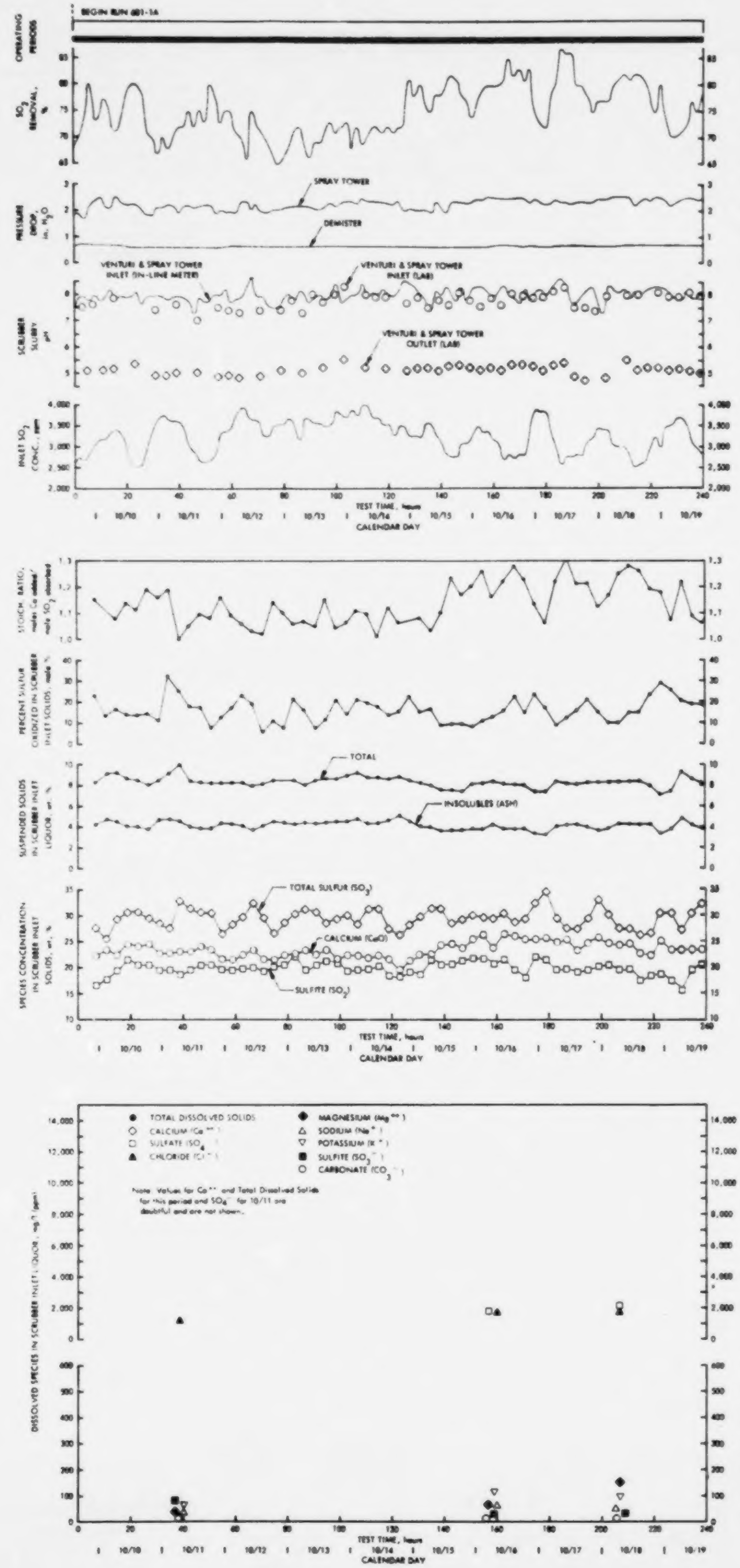
The test conditions for Run 601-1A were:

Gas Rate, acfm @ 330°F	25,000
Spray Tower Gas Velocity, ft/sec	6.3
Liquor Rate to Venturi, gpm	600
Liquor Rate to Spray Tower, gpm	1200
Venturi Liquid-to-Gas Ratio, gal/mcf	32
Spray Tower Liquid-to-Gas Ratio, gal/mcf	64
Percent Solids Recirculated	8
Effluent Residence Time, min.	12
Number of Spray Headers	4
Venturi Pressure Drop, in. H_2O	9
Spray Tower Pressure Drop, in. H_2O	2.5
Scrubber Inlet pH (Controlled)	8.0

On October 28 the system was shut down for 24 hours due to a problem with the lime slaker and on November 7 there was a 15 hour scheduled shutdown for an inspection (after 666 on-stream hours). The November 7 inspection revealed a very clean scrubber, except for minor scale and solid deposits in parts of the flooded elbow (between the venturi and spray tower and the upper half of the scrubber). However, occasional cleaning of accumulated scale from the venturi tangential nozzles was required. All the bottom demister vanes were clean while the top vanes were about 5 percent plugged with soft mud-like solids. This minor pluggage was not considered to be serious. Downstream of the demister some scattered solids-deposits (1/16 inch deep) were observed on the duct between the demister and the reheater and on the fan inlet dampers. Aside from these minor deposits, both the fan and outlet duct were clean.

Throughout this initial portion of the run (till the November 7 inspection), the clarifier was used as the final dewatering device. This resulted in an average percent solids discharged of 23 percent, which is somewhat lower than desired. The desirable solids concentration to be discharged is 40 percent or greater.

Graphical representation of the operating data for the first 30 days of Run 601-1A is given in Figure 5-1. As can be seen, the control of scrubber inlet pH and stoichiometry was not as good during the first 20 days of operation as during the latter 10 days. A summary of the operating data for lime Run 601-1A, as of the November 7 inspection, is as follows:

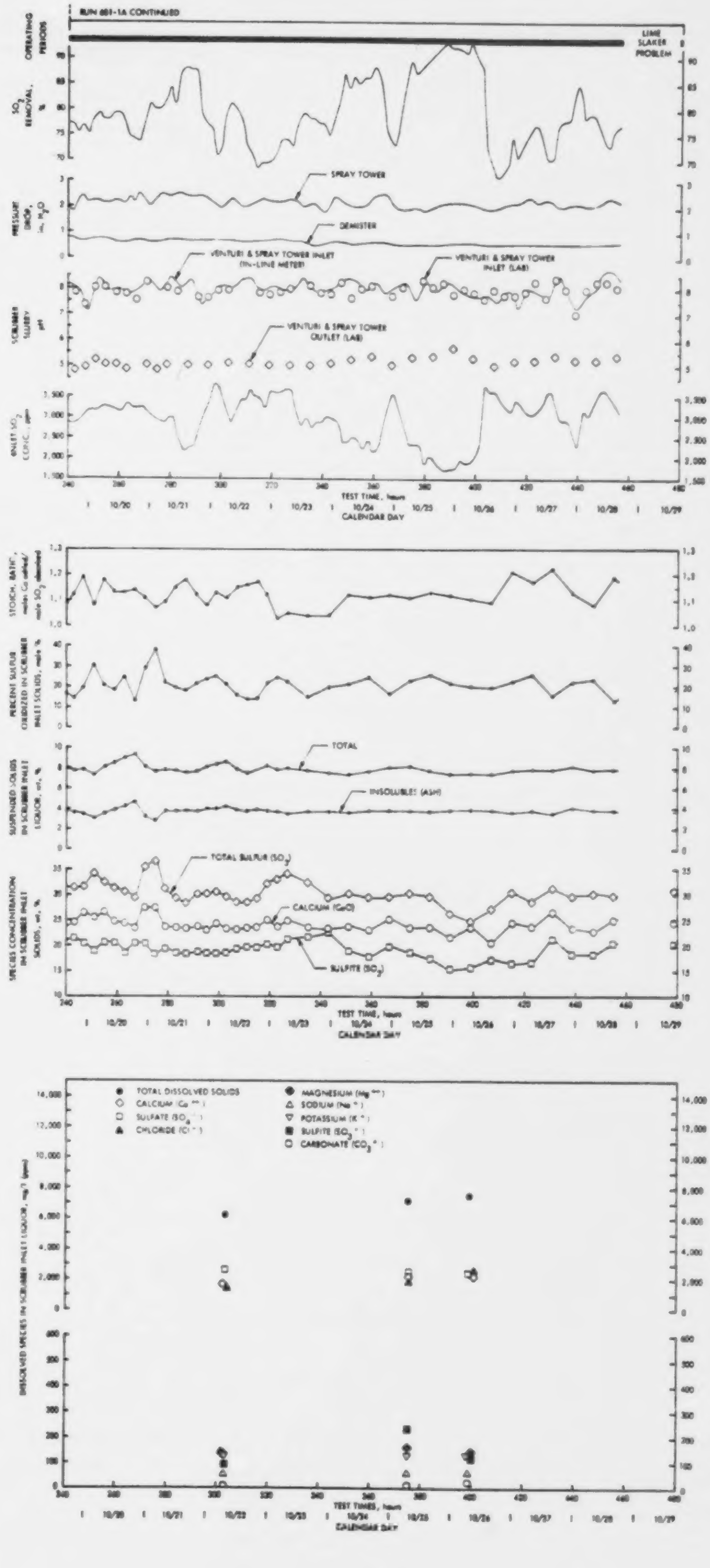


Gas Rate = 25,000 acfm @ 330 °F
Liquor Rate to Venturi = 600 gpm
Liquor Rate to Spray Tower = 1200 gpm
Venturi L/G = 32 gal/mcf
Spray Tower L/G = 64 gal/mcf
Spray Tower Gas Velocity = 8.3 ft/sec
Venturi Pressure Drop = 9 in. H_2O
E.H.T. Residence Time = 12 min
No. of Spray Headers = 4

Scrubber Inlet Liquor Temp. = 120-125 °F
Liquid Conductivity = 3,700-5,200 μ mhos/cm
Discharge (Clarifier) Solids Conc. = 21-26 wt %

Figure 5-1

OPERATING DATA FOR VENTURI RUN 601-1A

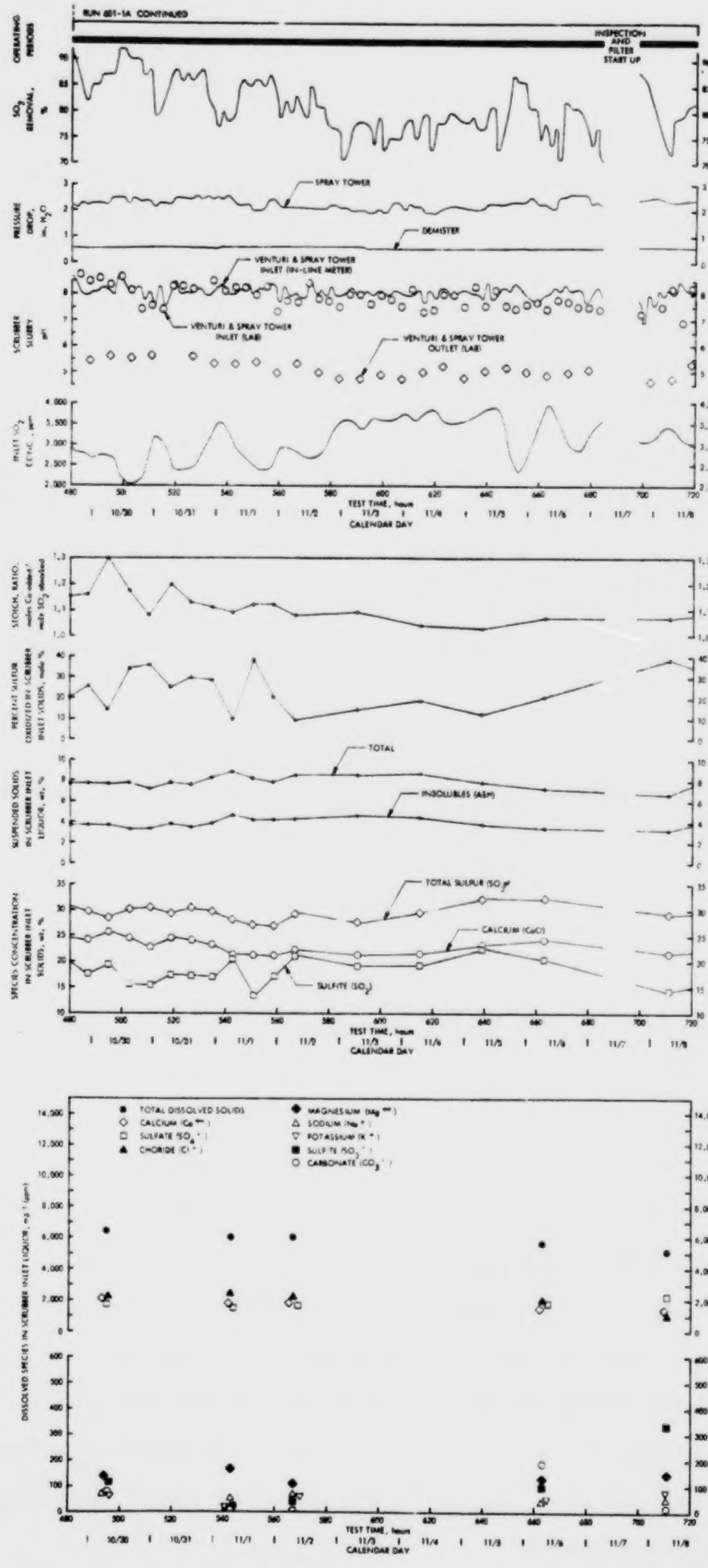


Gas Rate = 25,000 acfm @ 330 °F
Liquor Rate to Venturi = 600 gpm
Liquor Rate to Spray Tower = 1200 gpm
Venturi L/G = 32 gal/mcf
Spray Tower L/G = 64 gal/mcf
Spray Tower Gas Velocity = 8.3 ft/sec
Venturi Pressure Drop = 9 in. H_2O
E.H.T. Residence Time = 12 min
No. of Spray Headers = 4

Scrubber Inlet Liquor Temp. = 123-128 °F
Liquid Conductivity = 6,200-8,000 μ mhos/cm
Discharge (Clarifier) Solids Conc. = 22-28 wt %

Figure 5-1 (Continued)

OPERATING DATA FOR VENTURI RUN 601-1A



Gas Rate = 25,000 acfm @ 330 °F
Liquor Rate to Venturi = 600 gpm
Liquor Rate to Spray Tower = 1200 gpm
Venturi L/G = 32 gal/mcf
Spray Tower L/G = 64 gal/mcf
Spray Tower Gas Velocity = 8.3 ft/sec
Venturi Pressure Drop = 9 in. H_2O
E.H.T. Residence Time = 12 min
No. of Spray Headers = 4

Scrubber Inlet Liquor Temp. = 123-126 °F
Liquid Conductivity = 5,800-6,400 μ mhos/cm
Discharge (Clarifier) Solids Conc. = 20-25 wt %

Figure 5-1 (Continued)

OPERATING DATA FOR VENTURI RUN 601-1A

On-Stream Hours as of November 7	666
Average Stoichiometric Ratio, moles Ca/moles SO_2 absorbed	1.10
Average Percent Lime Utilization	91
Average Percent SO_2 Removal	80
Inlet SO_2 Concentration, ppm	1600-4000
Scrubber Outlet pH Range	4.5-5.5
Solids Dewatering	Clarifier
Average Dissolved Solids, ppm	7000
Predicted Sulfate Saturation	150

It is of interest to note, from the data in Figure 5-1, the effect of SO_2 inlet concentration on SO_2 removal; a drop of SO_2 inlet concentration is invariably accompanied by an increase in SO_2 removal, and vice versa.

Subsequent to the November 7 inspection, system control remained excellent, despite the varying SO_2 inlet load; stoichiometric ratio was controlled between 1.02 and 1.16 and scrubber inlet pH between 7.8 and 8.4.

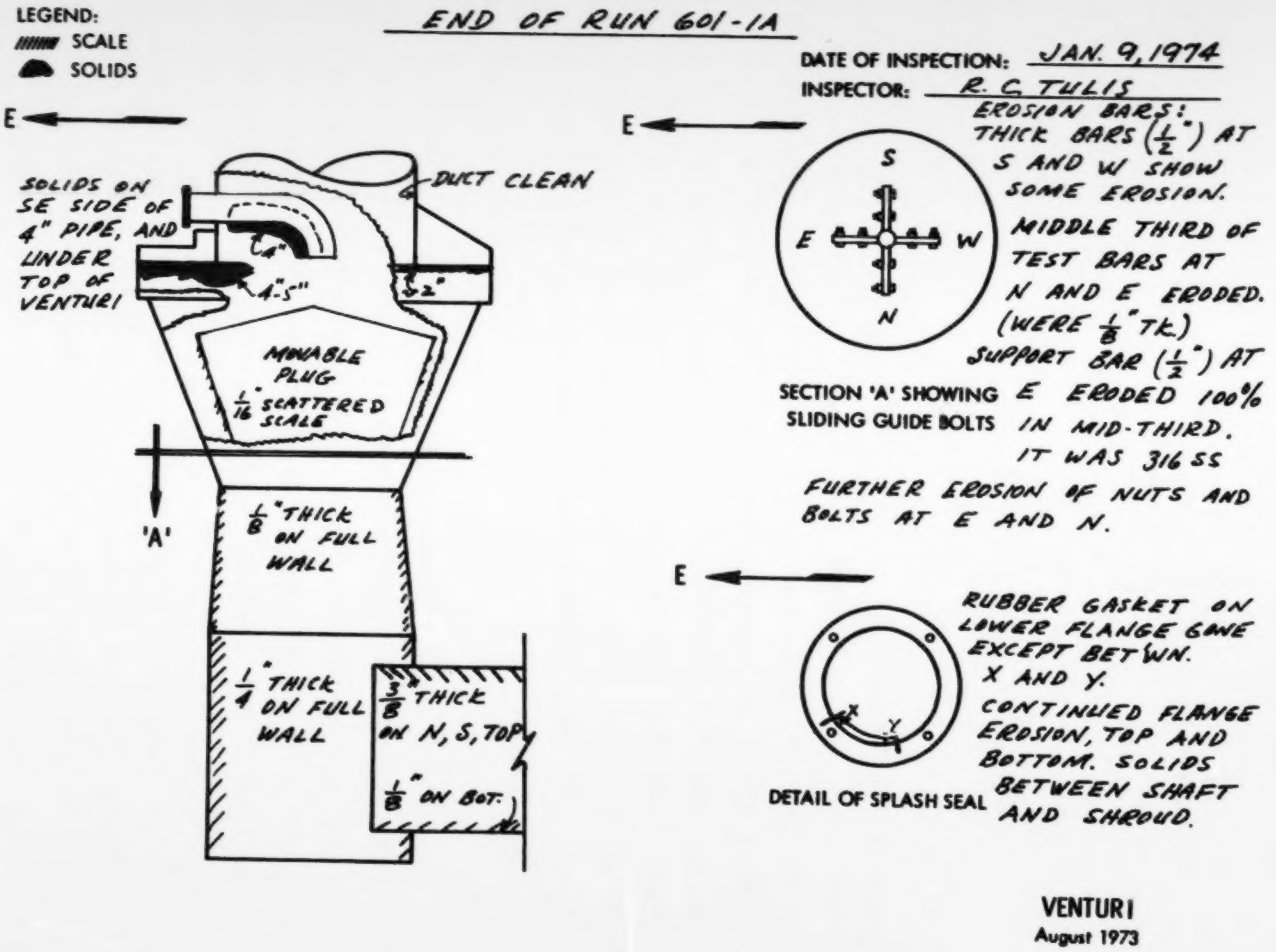
In order to evaluate the effect of higher percent solids discharged (higher dissolved solids concentration) upon system reliability, Run 601-1A was restarted on November 7 with the vacuum rotary drum filter in series with the clarifier. However, problems with the filter (filter cloth) resulted in intermittent operation of thid device and on November 23 the centrifuge was put in service. The centrifuge, however, also had mechanical difficulties (high vibration) and was taken out of service after a short while. On December 15, the filter was put back in service and remained in operation, with periodic replacement of the filter cloth, until the termination of the test. A summary of the operating data for Run 601-1A, with both the clarifier and filter in service for dewatering, is as follows:

On-Stream Hours with Clarifier and Filter	1487
Average Stoichiometric Ratio, moles Ca/moles SO_2 absorbed	1.11
Average Percent Lime Utilization	90
Average SO_2 removal	85
Inlet SO_2 Concentration, ppm	1700-4000
Scrubber Outlet pH Range	4.6-5.4
Solids Dewatering	Clarifier/Filter
Average Dissolved Solids, ppm	11,000
Predicted Sulfate Saturation	190

Throughout Run 601-1A, the pressure drop across the chevron demister had been somewhat variable (0.63 ± 0.1 inches H_2O) and, after about December 1, 1973, there was a continual increase. On January 8, 1974, Run 601-1A was terminated after 2153 hours (3 months) of on-stream operation due to high I.D. fan vibration. The pressure drop across the demister had increased from about 0.6 to about 1.65 inches H_2O. An inspection was conducted on January 9 and the accumulation of scale and solids within the scrubber system is shown in Figures 5-2 and 5-3.

The mist eliminator was substantially blocked, partly by solids that had fallen down from the outlet duct work and partly by scale formation, mainly on the bottom (inlet) vanes. The bottom demister vanes were covered with 30 to 40 mil scale. The outlet ducting between the reheater and I.D. fan damper was covered with from 1 to 3 inches of solids.

The shell of the spray tower was covered with a 3/8 inch thick sulfate scale below the bottom spray header and a 1/8 inch thick sulfate scale between the top and bottom spray headers. The rubber lining was visible in an approximate 2-1/2 ft wide band immediately below the demister. Noticeable scale and solids buildup occurred on the tips of


LEGEND:
SCALE
SOLIDS
E
E
E
DUCT CLEAN
4"
4"-5"
2"
MOVABLE PLUG
$\frac{1}{16}$" SCATTERED SCALE
'A'
$\frac{1}{8}$" THICK ON FULL WALL
$\frac{1}{4}$" THICK ON FULL WALL
$\frac{3}{8}$" THICK ON N, S, TOP
$\frac{1}{8}$" ON BOT.
S
E
W
N
X
Y
VENTURI
August 1973

END OF RUN 601-1A

DATE OF INSPECTION: JAN. 9, 1974
INSPECTOR: R. C. TULIS

SOLIDS ON SE SIDE OF 4" PIPE, AND UNDER TOP OF VENTURI

EROSION BARS: THICK BARS ($\frac{1}{2}$") AT S AND W SHOW SOME EROSION. MIDDLE THIRD OF TEST BARS AT N AND E ERODED. (WERE $\frac{1}{8}$" TK.) SUPPORT BAR ($\frac{1}{2}$") AT E ERODED 100% IN MID-THIRD. IT WAS 316 SS

SECTION 'A' SHOWING SLIDING GUIDE BOLTS

FURTHER EROSION OF NUTS AND BOLTS AT E AND N.

RUBBER GASKET ON LOWER FLANGE GONE EXCEPT BET'WN. X AND Y. CONTINUED FLANGE EROSION, TOP AND BOTTOM. SOLIDS BETWEEN SHAFT AND SHROUD.

DETAIL OF SPLASH SEAL

Figure 5-2. Venturi Inspection

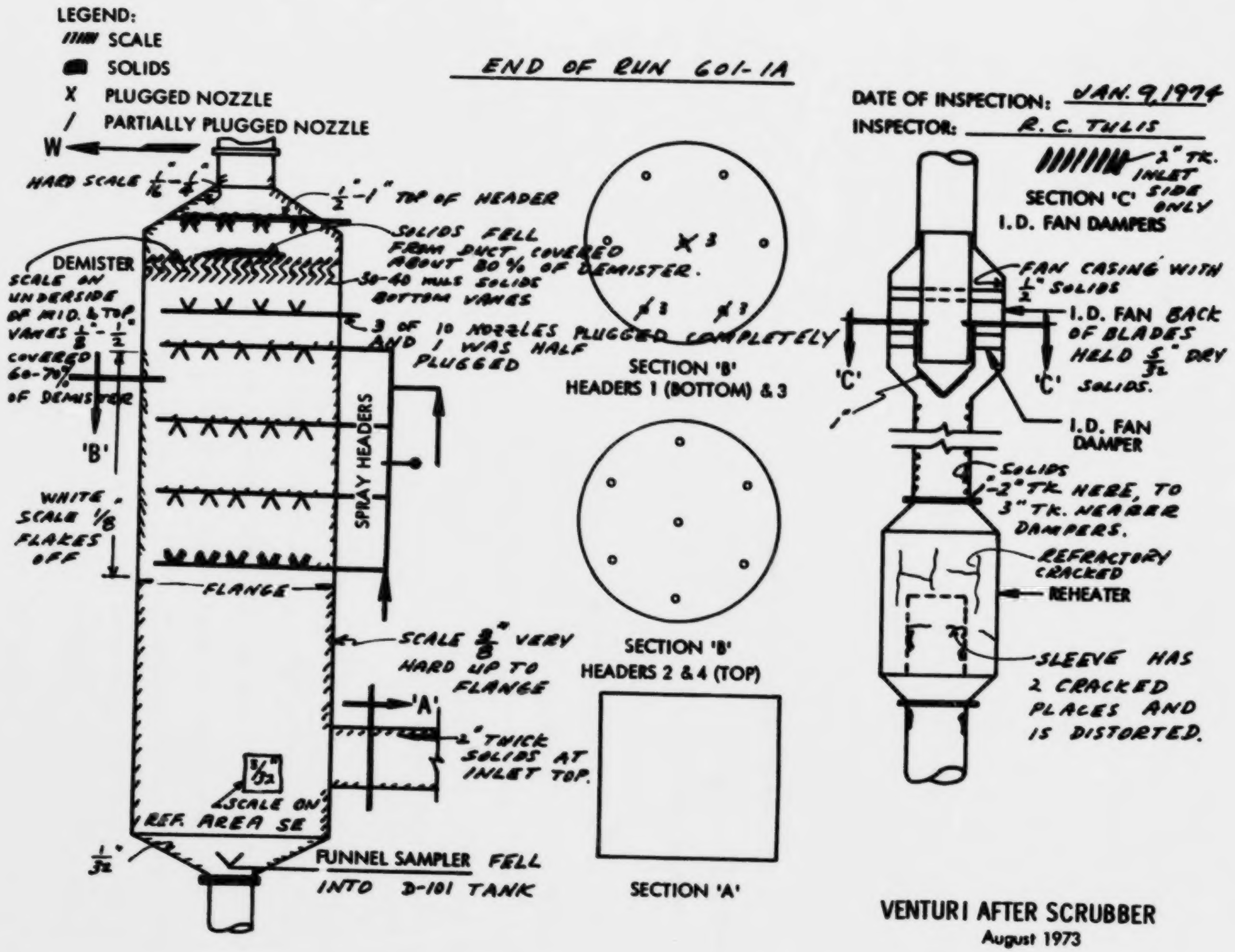

LEGEND:
//// SCALE
▬ SOLIDS
X PLUGGED NOZZLE
/ PARTIALLY PLUGGED NOZZLE
END OF RUN 601-1A
DATE OF INSPECTION: JAN. 9, 1974
INSPECTOR: R. C. TULIS
W
HARD SCALE 1/16"-1/8"
1/2"-1" TOP OF HEADER
SOLIDS FELL FROM DUCT COVERED ABOUT 80% OF DEMISTER.
DEMISTER
SCALE ON UNDERSIDE OF MID. & TOP. VANES 1/8"-1/2" COVERED 60-70% OF DEMISTER
30-40 MILS SOLIDS BOTTOM VANES
3 OF 10 NOZZLES PLUGGED COMPLETELY AND 1 WAS HALF PLUGGED
SPRAY HEADERS
'B'
WHITE SCALE 1/8 FLAKES OFF
FLANGE
SCALE 3/8" VERY HARD UP TO FLANGE
'A'
2" THICK SOLIDS AT INLET TOP.
3/32"
SCALE ON REF. AREA SE
1/32"
FUNNEL SAMPLER FELL INTO D-101 TANK
X 3
/ 3
/ 3
SECTION 'B'
HEADERS 1 (BOTTOM) & 3
SECTION 'B'
HEADERS 2 & 4 (TOP)
SECTION 'A'
//// 2" TK. INLET SIDE ONLY
SECTION 'C'
I.D. FAN DAMPERS
FAN CASING WITH 1/2" SOLIDS
I.D. FAN BACK OF BLADES HELD 5/32" DRY SOLIDS.
'C'
'C'
1"
I.D. FAN DAMPER
SOLIDS 1-2" TK. HERE, TO 3" TK. NEARER DAMPERS.
REFRACTORY CRACKED
REHEATER
SLEEVE HAS 2 CRACKED PLACES AND IS DISTORTED.
VENTURI AFTER SCRUBBER
August 1973

Figure 5-3. Spray Tower Inspection

several of the spray nozzles, especially on the bottom header. Some of the Bete stainless steel ST-48 FCN spiral tip nozzles were found to be significantly eroded after approximately 4300 hours of slurry service; of a total of 28 nozzles, 9 were severely eroded and 15 were considerably worn.

Light 1/16 inch thick scale covered the venturi plug and a 1/8 to 1/4 inch thick scale covered the venturi walls below the plug. A 1/8 to 3/8 inch thick scale covered the walls of the flooded elbow.

About 3/16 inch thick sulfate scale was found in the rubber lined circulating slurry piping. Scale buildup, varying from 1/64 to 1/8 inch in thickness, was also noted in the rubber lined variable speed pumps.

It should be noted that scale formation in the venturi, spray tower, circulating slurry piping and pumps did not prevent continual operation of the system or necessitate termination of the 3-month long lime reliability test. However, scale particles in nozzles and strainers required periodic maintenance.

It seems likely that the scale formation occurred, primarily, during the latter portion of the test, when the clarifier and filter were used for solids dewatering and the calculated liquor sulfate saturation was about 190 percent. As mentioned previously, an earlier inspection of the system on November 7, 1973, revealed a relatively scale-free scrubber system. Prior to this inspection the calculated liquor sulfate saturation was 150 percent.

The next long-term lime reliability test will be made under conditions intended to reduce recirculating liquor sulfate supersaturation and the accumulation of solids in the outlet duct-work. Sulfate supersaturation can be reduced (1) by decreasing oxidation of sulfite to sulfate, (2) by increasing percent solids recirculated, and (3) by increasing effluent residence time. Oxidation can be reduced by increasing the scrubber inlet liquor pH and/or by sealing the effluent hold tank. Also, the eroded stainless Bete spiral tip spray nozzles in the spray tower will be replaced by Stellite-tipped Bete spray nozzles for the next test.

Section 6

TEST RESULTS FROM THE EPA PILOT FACILITY AT RESEARCH TRIANGLE PARK

It is recognized that operating reliability is crucial to the successful application of limestone and lime scrubbers to utility boilers. This fact was the central consideration in planning an experimental program for the EPA pilot facility at Research Triangle Park. The approach to the reliability question assumes that scaling by calcium sulfate and sulfite is one of the most important problems. Therefore, the primary objective is to identify the operating conditions that eliminate scale formation. The secondary objective is to maximize the limestone and lime utilization, which will strongly influence operating cost when reliability is established. This section summarizes progress toward the improvement of process performance in these two areas.

6.1 DESCRIPTION OF EQUIPMENT AND OPERATION

Two 300-cfm scrubbers are operated concurrently with flue gas obtained from a natural gas/oil-fired boiler. Sulfur dioxide is fed from cylinders to provide a constant inlet concentration of 3000 ppm. One TCA scrubber is operated with lime, while the other with limestone obtained from the Shawnee test facility. Limestone tests are conducted in both TCA and multigrid scrubber configurations. Except for selected tests, fly ash is not present in the slurry and the liquor is free of chloride. Both scrubbers operate with closed liquor loop using a rotary drum filter for solids disposal (about 63 percent solids in sludge discharge).

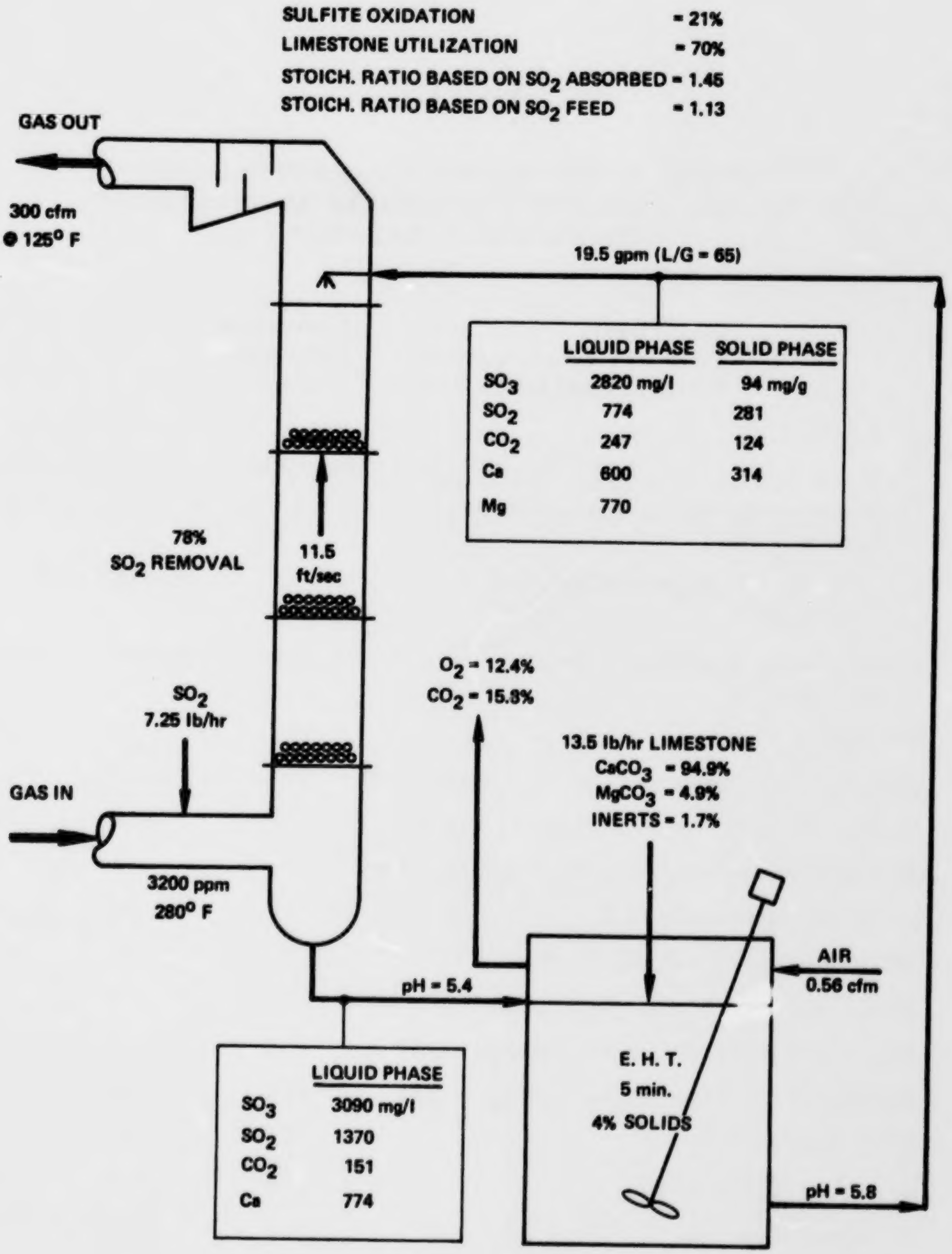
6.2 MATERIAL BALANCES AS A BASIS FOR EVALUATING PERFORMANCE

It is essential that the primary reactions that occur in the two process components, the scrubber and effluent hold tank, be determined from among the various possibilities that have been proposed. For this purpose, extensive material balances were made on limestone scrubbers over a range of operating conditions. Typical analytical data acquired for these material balances are indicated in Figure 6-1. In order to set up the simultaneous equations that will define all reactions in both parts of the system, it is necessary to measure the rate of CO_2 evolution from the effluent hold tank. This was accomplished by sealing the tank and purging with air at a constant measured rate. Orsat analyses of the purged gases provide direct data on CO_2 evolution and O_2 absorption rates at the liquid surface in the tank. Table 6-1 illustrates the type of information obtained from such material balances. Among other things, the material balances show that: (1) under normal operating conditions (stoichiometry of 1.25 based on SO_2 feed) about 70 percent of the total limestone dissolution occurs in the scrubber; and, (2) most of the oxidation occurs in the hold tank, about 60 percent of the total with a TCA, and 80 percent of the total with a multigrid scrubber.

The reaction scheme consistent with the data from these material balances shows two principal reactions occurring in the scrubber:

$$SO_2 + H_2O \longrightarrow H^+ + HSO_3^- \qquad (6\text{-}1)$$

$$H^+ + CaCO_3 \longrightarrow Ca^{++} + HCO_3^- \qquad (6\text{-}2)$$


SULFITE OXIDATION = 21%
LIMESTONE UTILIZATION = 70%
STOICH. RATIO BASED ON SO_2 ABSORBED = 1.45
STOICH. RATIO BASED ON SO_2 FEED = 1.13
GAS OUT
300 cfm
@ 125° F
19.5 gpm (L/G = 65)
78%
SO_2 REMOVAL
11.5
ft/sec
O_2 = 12.4%
CO_2 = 15.8%
SO_2
7.25 lb/hr
13.5 lb/hr LIMESTONE
$CaCO_3$ = 94.9%
$MgCO_3$ = 4.9%
INERTS = 1.7%
GAS IN
3200 ppm
280° F
AIR
0.56 cfm
pH = 5.4
E. H. T.
5 min.
4% SOLIDS
pH = 5.8

	LIQUID PHASE	SOLID PHASE
SO_3	2820 mg/l	94 mg/g
SO_2	774	281
CO_2	247	124
Ca	600	314
Mg	770	

	LIQUID PHASE
SO_3	3090 mg/l
SO_2	1370
CO_2	151
Ca	774

Figure 6-1. Operating Data for Limestone Feed

Table 6-1

TYPICAL PERFORMANCE CHARACTERISTICS OF TCA AND MULTIGRID SCRUBBERS AS DETERMINED BY MATERIAL BALANCE

Absorbent: Limestone
Inlet SO_2 Concentration: 2800 ppm
Effluent Residence Time: 5 min.

	TCA	Multigrid	
	4% Solids	16% Solids	
Stoichiometric Ratio, moles $CaCO_3$/ mole SO_2 feed	1.13	1.25	2.5
E. H. T. O_2 Absorption Rate, acfm @ 93°F	0.035	0.035	0.014
E. H. T. CO_2 Evolution Rate, acfm @ 93°F	0.084	0.062	0.046
SO_2 Make Per Pass, mg/l	630	774	863
$CaCO_3$ Dissolution in E. H. T., mg/l	357	316	259
$CaCO_3$ Dissolution in Scrubber, mg/l	626	814	1090
Dissolution in Scrubber, % of total	64	72	81
Total Oxidation, mole %	21	27	23
SO_2 Oxidized in Scrubber, mg/l	57	44	139
Oxidation in E. H. T., % of total	57	78	30
SO_2 Ppted in Scrubber as $CaSO_3$, mg/l	-23	218	454
SO_3 Ppted in Scrubber as $CaSO_4$, mg/l	380	184	294
L/G, gal/mcf	65	48	48
Scrubber Effluent pH	5.4	5.8	6.2
Scrubber Feed pH	5.8	6.3	6.4

SO_2 absorption by Equation 6-1 is enhanced as a result of the dissolution of limestone by Equation 6-2. Dissolution of $CaSO_3$ does not occur as long as sufficient limestone is present to maintain the scrubber effluent pH above 5.4 (see Table 6-1). Dissolution of limestone by Equation 6-2 is completed in the scrubber effluent hold tank where it raises the pH. As a consequence of the increased pH the bisulfite equilibrium is shifted and sulfite is precipitated. In addition to Equation 6-2, the primary reactions in the effluent hold tank are:

$$HSO_3^- \rightleftharpoons H^+ + SO_3^= \qquad (6\text{-}3)$$

$$SO_3^= + Ca^{++} \longrightarrow CaSO_3 \qquad (6\text{-}4)$$

The net unreacted species from the above sequence of reactions (Equations 6-1 through 6-4) are H^+ and HCO_3^- which build up in the liquor returned to the scrubber at high pH (~6.3). The third major reaction in the scrubber thus occurs when the pH is again dropped by Equation 6-1; the lower pH shifts the bicarbonate equilibrium irreversibly to CO_2, completing the reaction cycle:

$$H^+ + HCO_3^- \longrightarrow CO_2 + H_2O \qquad (6\text{-}5)$$

The material balances show that about 90 percent of the CO_2 is released in the scrubber by Equation 6-5. The remainder is evolved from the effluent hold tank.

6.3 IMPROVEMENT OF LIMESTONE UTILIZATION

The slowest reaction in the reaction cycle (Equations 6-1 through 6-5) is the dissolution of limestone (Equation 6-2). Two important consequences result: (1) the rate of limestone dissolution controls the reactions that follow it in sequence; and, (2) the extent to which the dissolution and precipitation reactions go to completion in the effluent hold tank is determined by the kinetics of limestone dissolution in the effluent hold tank.

The rate of $CaSO_3$ precipitation is controlled by and directly related to the $CaCO_3$ dissolution rate. The kinetics of the overall rate-limiting reaction (Equation 6-2) can thus be examined by measurements of the rate of disappearance of SO_2 in the effluent hold tank. This was done in the pilot plant by operating at various effluent hold tank residence times, percent solids and limestone stoichiometries. Figures 6-2 and 6-3 summarize these data, showing $CaSO_3$ precipitation rate, r (mg SO_2/liter/min.), as a function of SO_2 concentration in the liquid phase, C_{SO_2} (mg SO_2/liter), and limestone density in suspension within the backmixed tank, $[CaCO_3]$ in g $CaCO_3$/liter. The analysis indicates that the overall reaction can be approximated by a rate expression that is second order in sulfite concentration and first order in $CaCO_3$ suspension density.

The high sensitivity of the dissolution/precipitation reaction to SO_2 concentration suggests that greater total conversion would be expected in a reactor without backmixing. This can be shown mathematically by integration of the standard reactor design equation with the indicated

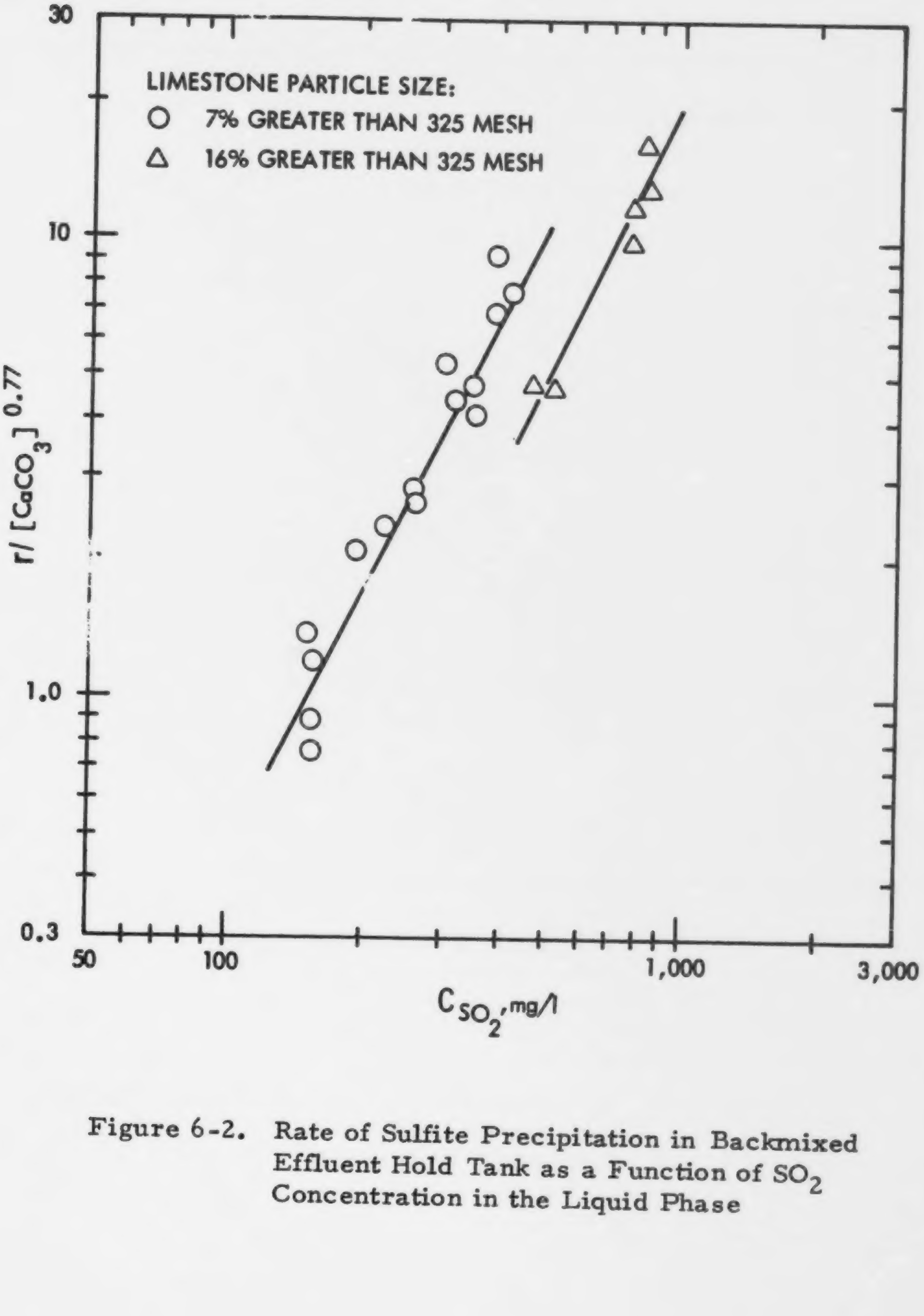


Figure 6-2. Rate of Sulfite Precipitation in Backmixed Effluent Hold Tank as a Function of SO_2 Concentration in the Liquid Phase

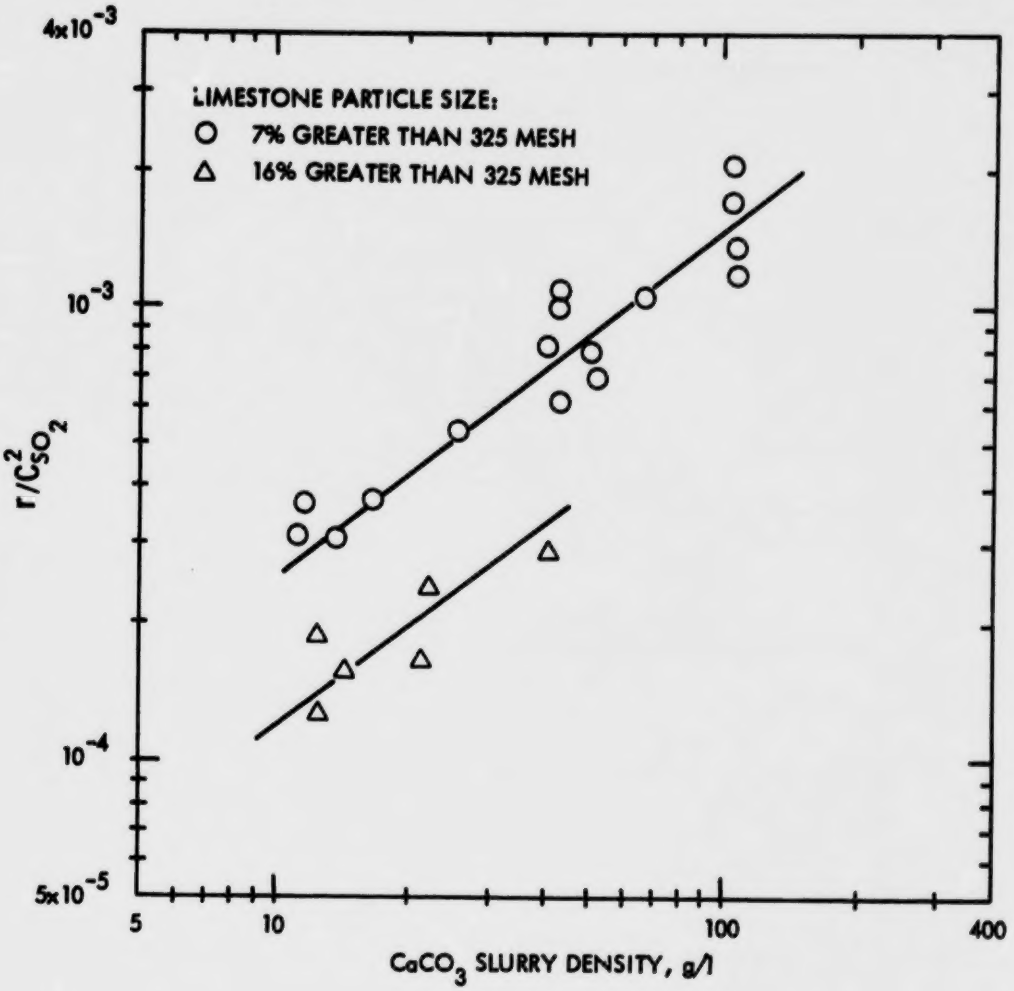


Figure 6-3. Rate of Sulfite Precipitation in Backmixed Effluent Hold Tank as a Function of CaCO$_3$ Slurry Density

second order rate expression for backmixed and plug-flow modes of operation. An experimental comparison of these two reactor types was carried out using vertical pipes arranged in a series of U-tubes as a plug-flow hold tank. As shown in Table 6-2 the normal 65-75 percent limestone utilization characteristic of backmixed effluent hold tanks was increased to 85-90 percent by plug-flow. Scrubber feed pH was likewise consistently higher in plug-flow tests.

6.4 FATE OF $MgCO_3$ IN LIMESTONE FEED

The limestone used in the pilot scrubber is the same as that used at the Shawnee test facility, and contains about 5 percent $MgCO_3$. Limestone utilizations are calculated on the basis of the total $CaCO_3$ content of the limestone. Since the $MgCO_3$ component is present as dolomite ($CaCO_3 \cdot MgCO_3$), a like number of moles of $CaCO_3$ is bound in this mineral form. Operating experience, based on Mg^{++} levels (ca. 700 ppm) observed in the closed-loop scrubbing liquor and petrographic analysis of the unreacted spent solid, indicates that a maximum of about 10 percent of the dolomite component of the limestone feed dissolves. The remaining solid dolomite passes through the scrubber without participating in any scrubber reactions. Thus, the utilization achievable with a dolomitic stone is less than that which can be expected with a pure limestone. Likewise, the spent sludge from the scrubber contains no leachable $MgSO_3$.

6.5 CONTROL OF SULFITE SCALING

Insofar as limestone dissolution kinetics controls the steady state liquor composition within the scrubber system, the rate of sulfite

Table 6-2

COMPARISON OF BACKMIXED AND PLUG-FLOW EFFLUENT HOLD TANK DESIGNS

Scrubber Type: Multigrid
Limestone: Shawnee (Fredonia), 16% +325 mesh

	Backmixed	Plug-Flow
SO_2 Feed Rate, lb/hr	4.84	4.93
Limestone Feed Rate, lb/hr (40% Slurry)	17.4	17.6
E. H. T. Residence Time, min.	6	6
Slurry Circulation Rate, gpm	12.7	12.7
Slurry Solids, %	7	7
Scrubber Feed pH	5.9	6.3
Scrubber Effluent pH	5.6	6.0
Scrubber Effluent Temperature, °F	127	134
Scrubber Feed Temperature, °F	126	124
SO_2 Feed Concentration, ppm	2930	3300
Stoichiometry (based on SO_2 feed)	0.87	0.87
Stoichiometry (based on SO_2 absorbed)	1.33	1.14
Percent SO_2 Removal	65.5	76.1
Limestone Utilization, %	75	88
Sulfite Oxidation, mole %	17	10
Ca^{++} in Scrubber Feed, mg/l	440	100

precipitation (Equation 6-4) exceeds that of limestone dissolution (Equation 6-2) and supersaturation by sulfite cannot occur. As indicated by the kinetic analysis, the limestone dissolution rate is accelerated by increasing the SO_2 concentration or suspended limestone density, or by reducing the limestone particle size. Should the limestone dissolution rate locally exceed the precipitation rate of $CaSO_3$, supersaturation and scaling of $CaSO_3$ can occur. Tests with the pilot scrubber at high limestone feed stoichiometries (which increase suspended limestone density) at L/G of 65 and 3000 ppm SO_2 in the inlet flue gas (which determine the effective SO_2 concentration in the scrubber liquor) showed excessive scaling of the scrubber walls by $CaSO_3$ when the scrubber effluent pH rose above 6.2. This condition corresponded to a stoichiometric ratio of 2.5 moles $CaCO_3$/mole SO_2 feed, with 93 weight percent of the limestone particles less than 325 mesh. As shown by Table 6-1, the proportion of $CaCO_3$ dissolution occurring in the scrubber is increased under these conditions. In some cases material balances showed as much as 90 percent of the total limestone dissolution occurring in the scrubber at high feed stoichiometry. In such situations nearly all of the reaction sequence is completed within the scrubber rather than delaying precipitation until the slurry reaches the effluent hold tank as is normally the case.

Reduction of the effluent hold tank residence time will, according to the reaction scheme discussed, build up the steady-state sulfite concentration in the liquor, accelerating the rate of dissolution to the point where it may no longer control the sulfite precipitation reaction. The scrubber feed can then become supersaturated. Experience indicates that this condition is not reached until the SO_2 concentration in the effluent hold tank liquor exceeds 800 mg/l which occurs only at very short residence times (less than 5 minutes). On this basis, residence times shorter than 7 minutes are not recommended with limestone scrubbing, particularly when oxidation is inhibited.

6.6 CONTROL OF SULFATE SCALING

As shown by the material balances, the dissolution of limestone in the scrubber increases the concentration of Ca^{++} by about 150 ppm at L/G of 65. When the scrubber feed is saturated with $CaSO_4 \cdot 2H_2O$ this represents a 25 percent increase in the calcium concentration at the bottom of the scrubber. Thus, even if no oxidation occurs, the scrubber effluent will be supersaturated with calcium sulfate. In a TCA scrubber, maximum supersaturation occurs at the first stage support grid and rapid scaling at this point has been experienced in the scrubbers with either limestone or lime feeds. In the absence of fly ash, the grid openings are plugged within 50 hours at L/G of 52. The presence of fly ash significantly reduces the rate of scaling, as does increasing L/G. Other factors, such as humidification of flue gas (128°F quench) and $CaSO_4$ seeding, had no appreciable effect when scrubbing flue gases containing 3000 ppm SO_2. It was concluded that L/G's must exceed 65 for TCA operation with saturated feed, and the presence of fly ash in the slurry is a positive benefit from the scale-control point of view.

A limestone or lime scrubber is customarily visualized as operating with two coexisting, but independent, liquid/solid systems involving precipitated $CaSO_3 \cdot 1/2\,H_2O$, crystallized $CaSO_4 \cdot 2H_2O$, and saturated mother liquor. Any sulfate generated by oxidation in the scrubber must, according to this view, build up in the recirculating solution until it is saturated with calcium sulfate. Crystallization of gypsum thereupon removes the sulfate from the system.

It was shown by Imperial Chemical Industries (I.C.I.) in 1951 that significant amounts of calcium sulfate are incorporated into the calcium sulfite crystal lattice when it precipitates from scrubber liquors. The amount of sulfate that could be so incorporated was experimentally established at 0.225 mole SO_3/mole SO_2 for precipitation in a limestone slurry. The resulting compound was referred to as a "solid solution." Although unsaturated operation of the I.C.I. Bankside scrubber was never reported, the formation of the solid solution clearly affords an alternate mechanism by which $CaSO_4$ can be purged from the system without crystallization. Thus, if the rate of generation of sulfate by oxidation is less than the rate at which sulfate is incorporated by the precipitating $CaSO_3$, the recirculating liquor is no longer constrained to saturation by calcium sulfate.

That a closed-loop scrubber can operate unsaturated by the above mechanism was first noted during the plug-flow hold tank experiments at the EPA pilot facility. Unsaturation was evidenced by steady state Ca^{++} concentrations of only 100 ppm in the scrubbing liquor (about 1/6 the level of saturation with $CaSO_4 \cdot 2H_2O$). Material balances confirmed closed-loop operation and direct dissolution of solid $CaSO_4 \cdot 2H_2O$ in the scrubber liquor proved unsaturation. Tests of the solid solution verified the characteristics reported by I.C.I., i.e., no detectable gypsum by x-ray diffraction, and no gypsum extractable by water. Therefore, the sulfate shown to be present by chemical analysis

(9-17 percent of total sulfur) does not exist as a separate phase. Confirmation of the presence of sulfate by chemical analysis was made by dissolution of the solid solution in HCl, extraction and recrystallization of pure gypsum from water in the amounts indicated by analysis. Intense x-ray peaks at d-values of 2.67 and 5.34 have also been noted, which are similar to those of calcium thiosulfate. Since thiosulfate was shown to be absent by chemical analysis, these peaks are probably characteristic of the solid solution.

Tests with the backmixed effluent hold tank showed that it could also be operated in the unsaturated mode by sealing the top of the tank to prevent air contact with the slurry. As indicated by the material balances, most oxidation occurs in the effluent hold tank. Sealing the tank eliminates this source and the total oxidation is reduced to about 10-15 percent (CO_2 evolution from the tank provides a self-generating blanket). Unsaturation of the liquor occurs when the oxidation falls below the level corresponding to the maximum SO_3/SO_2 ratio in the solid solution.

The oxidation level at which unsaturation occurs is shown in Figure 6-4 where calcium concentrations of the scrubber feed liquor are plotted over the full range of oxidation in which the pilot plant has been operated. It is clear that calcium concentrations correspond to saturated $CaSO_4 \cdot 2H_2O$ above 19 percent oxidation and drop progressively as oxidation is reduced below that level. The relationship between oxidation and the SO_3/SO_2 mole ratio in the solid is given by:

$$\begin{aligned}\text{Sulfite Oxidation} &= SO_2 \text{ Oxidized}/(SO_2 \text{ Oxidized} + SO_2 \text{ Precipitated}) \\ &= \text{Ratio}/(\text{Ratio} + 1)\end{aligned} \qquad (6\text{-}6)$$

where

Ratio = SO_3/SO_2 mole ratio in solid

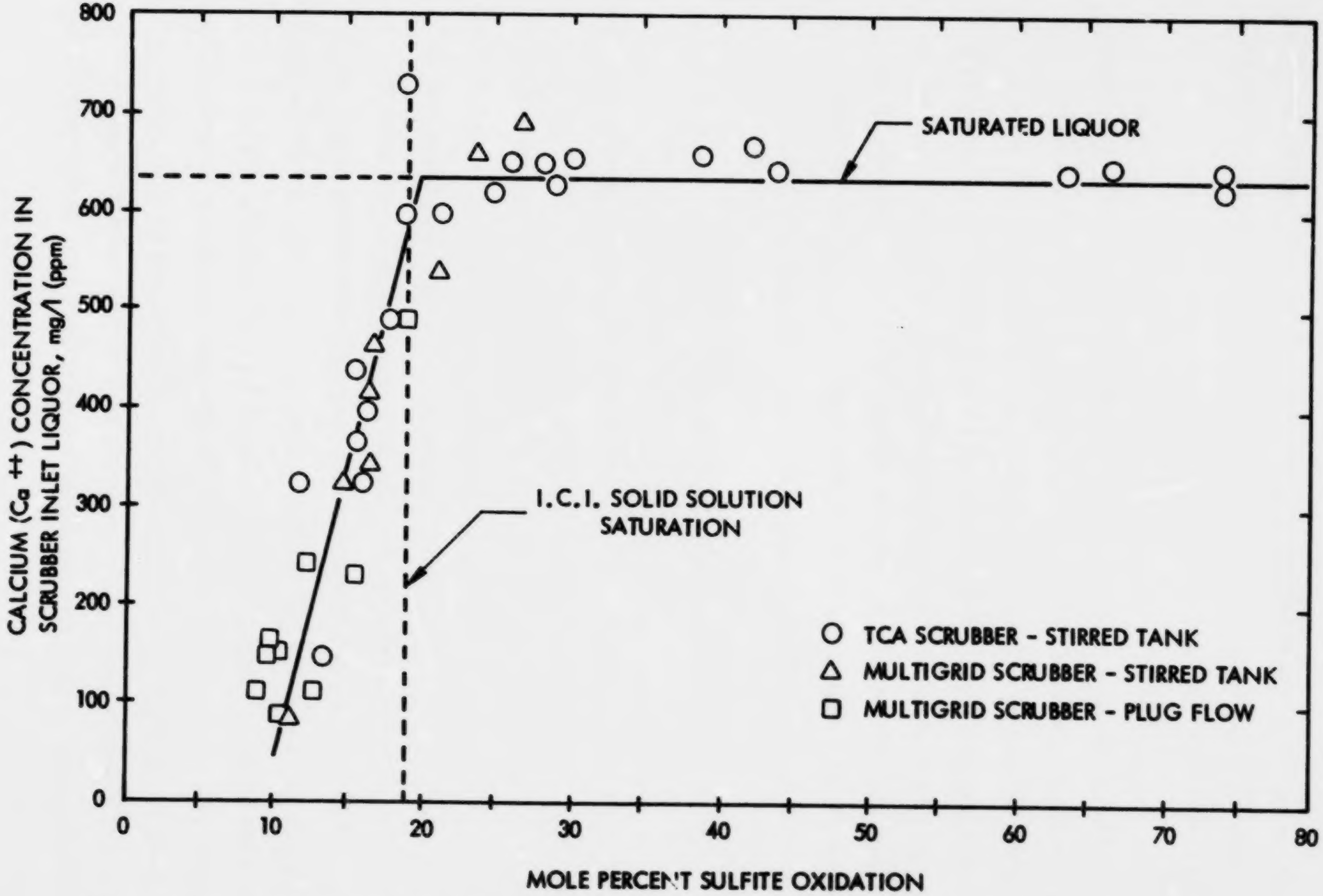


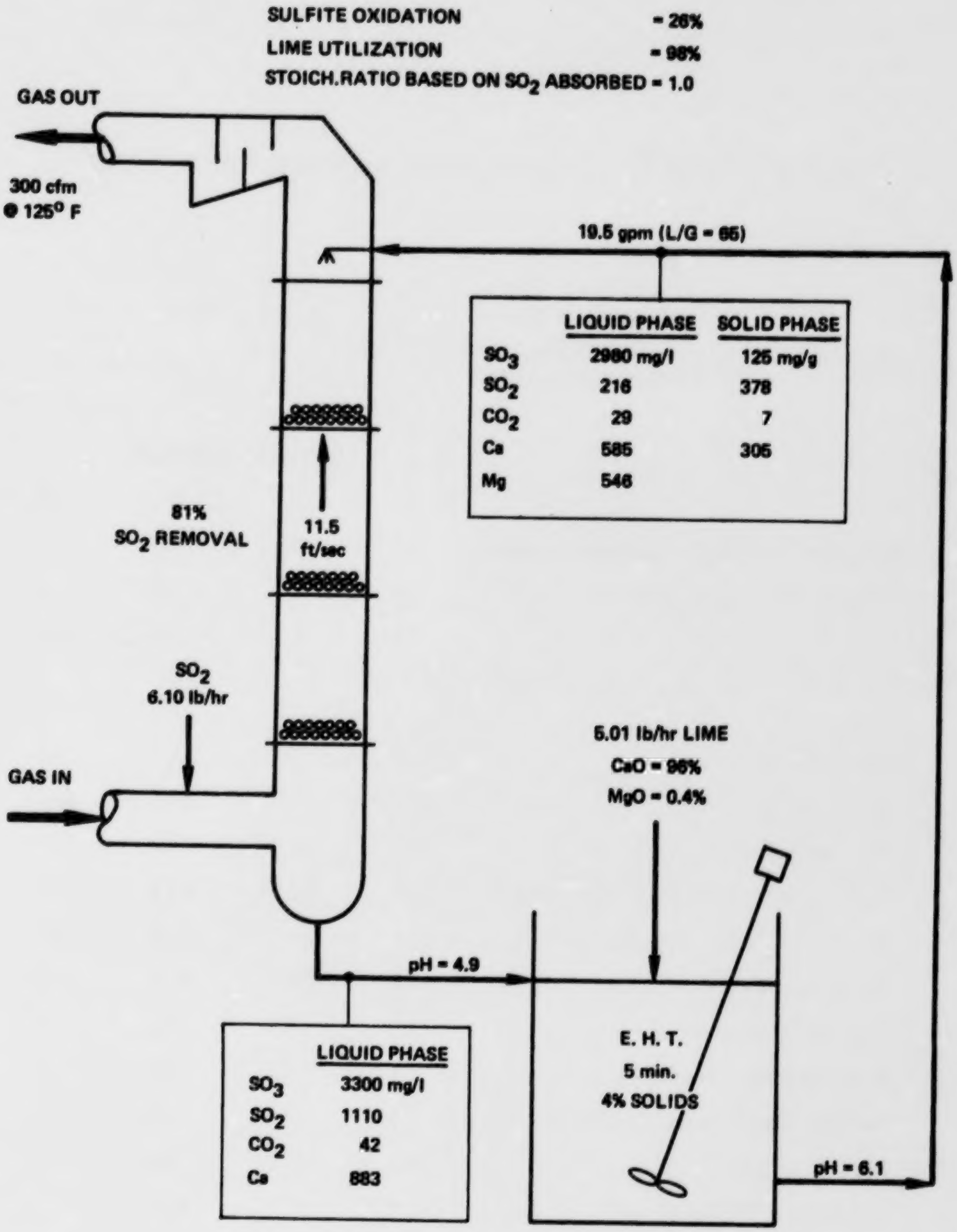
Figure 6-4. Calcium Sulfate Saturation as a Function of Sulfite Oxidation in Scrubbers Operating with Limestone: Chloride Concentration = 0

Therefore, 19 percent oxidation corresponds to the maximum SO_3/SO_2 mole ratio of 0.23, which is in good agreement with the value obtained by I.C.I. from laboratory measurements.

Elimination of sulfate supersaturation of the scrubber effluent liquor by operation in an unsaturated mode has been demonstrated in the TCA pilot scrubber with both limestone and lime feeds. In either case, the limitation of oxidation below 19 percent is the critical condition for desaturation. Other factors that may affect solid solution formation and the ability to operate unsaturated, particularly in the presence of high concentrations of chloride, are less well defined. The current work at the EPA pilot facility is focused in this area.

6.7 UTILIZATION IN LIME SCRUBBERS

When CaO is the scrubber feed rather than $CaCO_3$, dissolution kinetics is no longer a constraint and higher utilizations can be achieved in a stirred tank of given residence time. Comparison of Figure 6-1 (limestone) and Figure 6-5 (lime) illustrates the difference at scrubber feed pH of about 6 for 5 minutes residence time and 4 percent solids. For lime scrubbing, raising the scrubber feed pH will increase the amount of CO_2 absorbed from the flue gas and utilization drops as $Ca(OH)_2$ is recarbonated to $CaCO_3$. This side reaction must be limited if the advantage of CaO over $CaCO_3$ is to be maintained. Table 6-3 summarizes a series of tests made in the pilot scrubber to determine the effect of feed pH on lime utilization. The values of utilization shown are based on the solids analysis and do not reflect losses in the slaking step, which average about 4 percent of the total CaO content


SULFITE OXIDATION = 26%
LIME UTILIZATION = 98%
STOICH.RATIO BASED ON SO_2 ABSORBED = 1.0
GAS OUT
300 cfm
@ 125° F
19.5 gpm (L/G = 65)
81%
SO_2 REMOVAL
11.5
ft/sec
SO_2
6.10 lb/hr
GAS IN
5.01 lb/hr LIME
CaO = 96%
MgO = 0.4%
pH = 4.9
E. H. T.
5 min.
4% SOLIDS
pH = 6.1

	LIQUID PHASE	SOLID PHASE
SO_3	2980 mg/l	125 mg/g
SO_2	216	378
CO_2	29	7
Ca	585	305
Mg	546	

	LIQUID PHASE
SO_3	3300 mg/l
SO_2	1110
CO_2	42
Ca	883

Figure 6-5. Operating Data for Lime Feed

Table 6-3

EFFECT OF FEED pH ON LIME SCRUBBER OPERATION

Scrubber Type: TCA
Pressure Drop: 6.5 in. H_2O
Effluent Residence Time: 5 min.
Percent Solids: 4%

	Scrubber Feed pH			
	6	7	9	10
CO_2 in Scrubber Effluent, mg/l	42	43	47	68
CO_2 in Scrubber Feed, mg/l	29	26	25	8
CO_2 Precipitated in E.H.T., mg/l	13	17	22	60
CO_2 in Solid, mg/g	7	14	33	37
Lime Utilization, %	98	97	89	81
Ca^{++} in Scrubber Feed, mg/l	585	570	845	896
SO_2 Make Per Pass, mg/l	506	569	500	570
ΔSO_2 Across Scrubber mg/l	732	866	674	600
ΔSO_2 - Make Per Pass, mg/l	226	297	174	30
ΔCa Across Scrubber, mg/l	298	255	240	136
SO_2 in Scrubber Feed, mg/l	216	188	64	33
Percent SO_2 Removal	81*	78	80	84
Sulfite Oxidation, mole %	26	20	19	13
Mg^{++}, mg/l	546	1000	40	5
Scrubber Effluent pH	4.9	5.1	5.1	5.0

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* ΔP = 8.5 in.

of pebble lime. It is clear from Table 6-3 that recarbonation is significant at inlet pH of 9 and above. Also, magnesium is precipitated from the liquor at pH of 9. These facts indicate that the optimum scrubber inlet pH's are in the range of 7-8.

The data in Table 6-3 confirm the observation reported by others that the primary scrubbing reaction in the lime system is the dissolution of $CaSO_3$:

$$CaSO_3 + H^+ \longrightarrow Ca^{++} + HSO_3^- \qquad (6\text{-}7)$$

This is evidenced by the fact that the change in SO_2 concentration in liquid (ΔSO_2) across the scrubber exceeds the SO_2 make per pass in all cases together with the increase in Ca^{++} concentration across the scrubber.

It is notable that the reaction shown by Equation 6-5, which contributes to pH buffering in limestone scrubbers, does not occur in a lime system. Consequently the pH drops to a greater degree when SO_2 is absorbed. As indicated in Table 6-3, change in liquor pH across the scrubber (1-5 units) far exceeds the 0.5 unit typical of limestone scrubbers. This lack of buffering is presumed to be responsible for the generally lower SO_2 scrubbing efficiency that has been experienced with lime scrubbing at the EPA pilot facility, compared to limestone at a given pressure drop.

At SO_2 feed concentrations in excess of 2500 ppm, the increase in calcium concentration in the scrubber effluent resulting from $CaSO_3$ dissolution (Equation 6-7) is responsible for $CaSO_4$ supersaturation and TCA grid scaling in lime system, in the same manner as $CaCO_3$ dissolution (Equation 6-2) in limestone systems. The most effective technique for dealing with this problem appears to be the unsaturated mode of operation discussed in the previous section. Control of pH, oxidation and Mg^{++} concentration to yield an unsaturated scrubber feed and marginally saturated (to unsaturated) scrubber effluent is an achievable goal for either limestone or lime scrubber systems.

6.8 CONCLUSIONS

The following conclusions have been drawn from the limestone and lime results of the TCA pilot-plant testing at Research Triangle Park, with inlet SO_2 feed concentrations of 3000 ppm:

- For limestone scrubbing, control of the scrubber effluent pH below 6.2 will prevent calcium sulfite scaling.
- Optimum scrubber inlet pH (reasonable SO_2 removal and reasonable lime utilization) for lime scrubbing is in the 7-8 range.
- Limestone dissolution kinetics are improved by plug flow reaction; higher utilizations can be achieved by effluent hold tank designs such as U-tubes or a series of stirred tanks that approximate plug flow.
- For limestone scrubbing, dissolution of $CaCO_3$ is the rate controlling step for SO_2 absorption. For high-calcium lime scrubbing, dissolution of $CaSO_3$ is the rate controlling step.
- Hold tank residence time must exceed 5 minutes in a limestone system. 10 minutes appears to be a good choice. For a lime system, 5 minutes appears adequate.
- The scrubber effluent will always be supersaturated with $CaSO_4 \cdot 2H_2O$ when a scrubber is operated with saturated feed.

- Supersaturation is maximum at the first stage TCA support grid and rapid scaling of the grid by calcium sulfate occurs at liquid-to-gas ratios less than 65 gal/mcf with no fly ash in the system. The liquid-to-gas ratio must exceed 65 for reliable operation with saturated calcium sulfate feed.
- The presence of fly ash reduces the rate of scaling by calcium sulfate.
- Sulfate scaling can be eliminated by operating a scrubber in the unsaturated mode. Closed liquor loop unsaturated operation can be achieved in a chloride-free scrubber by reducing oxidation below 19 percent. Under these conditions the sulfate generated by oxidation is purged entirely as solid solution (i. e. calcium sulfate in calcium sulfite crystal lattice).
- For limestone scrubbing, oxidation is a controllable variable within the limits required for unsaturated operation. It can be reduced by eliminating air contact in the effluent hold tank (e. g., using sealed stirred tank or plug flow tank). Further reduction can be attained by circulating high percent solids (which affects the amount of liquor circulating through the clarifier or filter).
- Sulfate bound as solid solution is not extractable from the spent sludge by water leaching. Therefore, the potential for water pollution is reduced.
- The dolomitic component of limestone feeds is essentially inert and leaves the scrubber in the same form within the sludge.

Section 7

FINDINGS TO DATE

Based on Shawnee and EPA pilot facility testing to date, the following items are preliminary findings regarding (1) scrubber design and operating parameters, (2) process chemistry/advanced concepts, and (3) equipment/materials/instrumentation.

Scrubber Design and Operating Parameters

The TCA and the venturi/spray tower have potential for reliable operation for both limestone and lime scrubbing. Due primarily to nozzle wear problems, insufficient data has been generated on the Marble-Bed scrubber to assess its reliability potential under Shawnee conditions.

Conditions for best overall potential for reliable limestone scrubbing operation with configurations comparable to the Shawnee scrubber systems are: an effluent residence time equal to or greater than 10 minutes and a percent solids recirculated equal to or greater than 10 percent, for a liquid-to-gas ratio equal to or greater than 60 gal/mcf. Variables which appear particularly important are liquid-to-gas ratio and scrubber superficial gas velocity. Shawnee liquid-to-gas ratios should be considered minimum values, since there is evidence that values higher than attainable at Shawnee would further minimize the potential for scrubber scaling and increase SO_2 removal and limestone utilization. Superficial velocity is considered important since there appears to be a certain value above which excessive demister entrainment occurs. For the Shawnee demister/Koch tray configuration in the TCA, this maximum velocity appears to be about 8 ft/sec. The spray tower demister/wash system limitation appears to be about 6 ft/sec.

For lime scrubbing, the venturi/spray tower conditions which have given good results in the operation to date are: (1) a scrubber inlet pH of 8, (2) an effluent residence time of 12 minutes, (3) a percent solids recirculated of 8 percent (40 percent of solids is fly ash), and (4) a spray tower liquid-to-gas ratio of 64 gal/mcf. In addition to the importance of liquid-to-gas ratio and superficial gas velocity discussed for limestone systems, inlet scrubber pH is considered important in lime systems; the value of 8.0 has resulted in good performance.

The following factors should be effective in minimizing pluggage problems associated with chevron-type demisters: (1) minimize scrubber superficial velocity consistent with cost, turndown, space and other factors, (2) utilize a wash tray between the uppermost scrubber stage and demister, and (3) wash demister from upstream (bottomside) direction with a mixture of clarified liquor and all available makeup water and assure complete surface irrigation.

All three scrubbers have been effective dust collectors, since they have reduced inlet particulate loadings from about 2-5 grains/scf to 0.01-0.04 grains/scf.

Limited cascade impactor distribution data for the TCA indicates effective particulate removal in the submicron range. For example, at the highest pressure drop tested (9.7-9.9 inches H_2O), TCA removal efficiencies were about 95 percent in the 0.1 to 0.2 micron diameter size range; decreased pressure drops resulted in significantly reduced removal efficiencies. Further testing, however, is necessary to validate this apparent high performance in the submicron range.

It should be noted that combined scrubber collection of SO_2 and fly ash (no mechanical or ESP collection upstream of the scrubbers) seems to have a major disadvantage. Namely, that roughly 30-50 percent of slurry solids is fly ash, which appears to be the most abrasive solid component. Rubber lined components have shown little evidence of wear. The following components, however, appear particularly sensitive to erosion: TCA spheres, TCA support grids, slurry spray nozzles, centrifuge and venturi throat guide-vane assembly. Work with vendors is in progress to improve these components.

Although it is too early for a definitive finding concerning the relative advantages of lime versus limestone, the following are preliminary observations: (1) lime utilizations are substantially higher than limestone utilizations; in the order of 90-93 percent for lime vs. 65-75 percent for limestone, (2) pH control appears easier with lime since pH is more sensitive to alkali addition than in the limestone system, where the required excess is higher, and (3) preliminary at least, lime operation seems less prone to plugging and scaling problems, although reasons for this apparent difference are not well understood. As mentioned previously, the moisture content of the discharge slurry is higher than desired for the lime testing.

Process Chemistry/Advanced Concepts

Generally operation at Shawnee for both limestone and lime has yielded scrubbing liquors that were either saturated or supersaturated with respect to $CaSO_4 \cdot 2H_2O$ and $CaSO_3 \cdot 1/2H_2O$. The following combination of process variables appear effective in minimizing scaling potential: (1) high liquid-to-gas ratios, (2) greater than 1 percent $CaSO_4 \cdot 2H_2O$ seed crystals in slurry, and (3) effluent residence times greater than or equal to 10 minutes. To minimize demister scaling, dilution of demister or wash tray liquor with fresh water appears to be effective.

Research on the small pilot scrubber at EPA-RTP has indicated that it may be possible to operate in an unsaturated sulfate mode with respect to $CaSO_4 \cdot 2H_2O$, with potential freedom from gypsum scaling. Low oxidation is essential to operation in this mode.

Plug flow effluent hold tank designs appear substantially more effective than conventional stirred tanks in enhancing limestone utilization. They also help achieve unsaturated operation by reducing hold tank oxidation. Further work is necessary.

It has been determined that the dolomite fraction of dolomitic limestone is very slowly soluble and does not supply alkalinity under normal scrubber operating conditions.

With properly calcined dolomite, magnesium does go into solution and, when using dolomitic limes, SO_2 removal efficiencies are substantially enhanced; this appears to be due to the increased amounts of solution alkalinity in the form of magnesium sulfite (relative to sulfurous acid).

In limestone systems it is important to avoid high stoichiometries with corresponding high pH's, because $CaSO_3 \cdot 1/2H_2O$ formed in the scrubber precipitates and can lead to scaling. Lower limestone stoichiometries are also effective in enhancing limestone utilizations, since limestone dissolution is much more rapid at the lower pH's.

It appears practicable to substantially increase oxidation by air sparging in the stirred hold tank; this could lead to improved sludge characteristics. Further evaluation is necessary.

The scrubbers are effective in absorbing HCl from the flue gas (coal has from 0.1 to 0.3 percent Cl) leading to relatively high liquor chloride levels during closed loop operation. Although the effects of chloride are not well understood, they appear, for example, to significantly decrease scrubber pH with subsequent loss in absorption performance.

Equipment/Materials/Instrumentation

Rubber lined, variable speed, centrifugal pumps with Hydroseals or Centriseals are reliable for slurry service.

For a fuel oil fired reheater, an isolated or external combustion chamber should be used to avoid quenching of the reheater flame by cold flue gas.

The rubber linings of the scrubbers, pumps, pipes, etc., give satisfactory erosion and corrosion resistances for slurry and flue gas (quenched) services. Flakeline linings on the effluent hold tanks and clarifiers are also satisfactory.

Type 316L stainless steel gives much better corrosion resistance than type 304L in slurries containing chlorides.

A centrifuge gives satisfactory dewatering capability. However, erosion on the metal surfaces is a major problem.

The dewatering and cake discharge capabilities of the filter, using a nylon filter cloth, are satisfactory. However, the useful life of the nylon filter cloth tested to-date is unsatisfactory.

Uniloc Model 321 submersible type pH meters gives better performance than Model 320 in-line flow-through types.

The performance of Ohmart radiation-type and bubble-type density meters is unsatisfactory. The performance of Dynatrol density meters has thus far been encouraging.

Control valves in slurry service have generally been unsatisfactory. Variable speed pumps should be used for slurry flow control.

Section 8

FUTURE TEST PLANS AT THE SHAWNEE FACILITY

Planning has been performed to formulate a follow-up test program to the present Shawnee activities. It should be noted that these plans are quite preliminary in nature; they require additional funding which has not officially been authorized and hopefully will be modified based on utility and vendor inputs. Figure 8-1 presents the overall test schedule for advanced limestone and lime testing which will extend the present program through June 1976. The following are the objectives of the advanced program:

- Evaluate the effectiveness of automatic control systems for scrubbers experiencing widely varying flue gas flow rates and inlet SO_2 concentrations.
- Investigate advanced process variations which offer promise of enhanced reliability by completely eliminating potential for gypsum scaling.
- For limestone systems, evaluate process variations which offer potential for substantial increases in limestone utilization, with subsequent decrease in sludge production.
- For limestone and lime systems determine the upper limit of SO_2 removal efficiencies within the constraints of facility scrubber configuration, pressure drop and liquid flow rate limitations. This may be important if future air pollution regulations require more stringent SO_2 control for power plants.

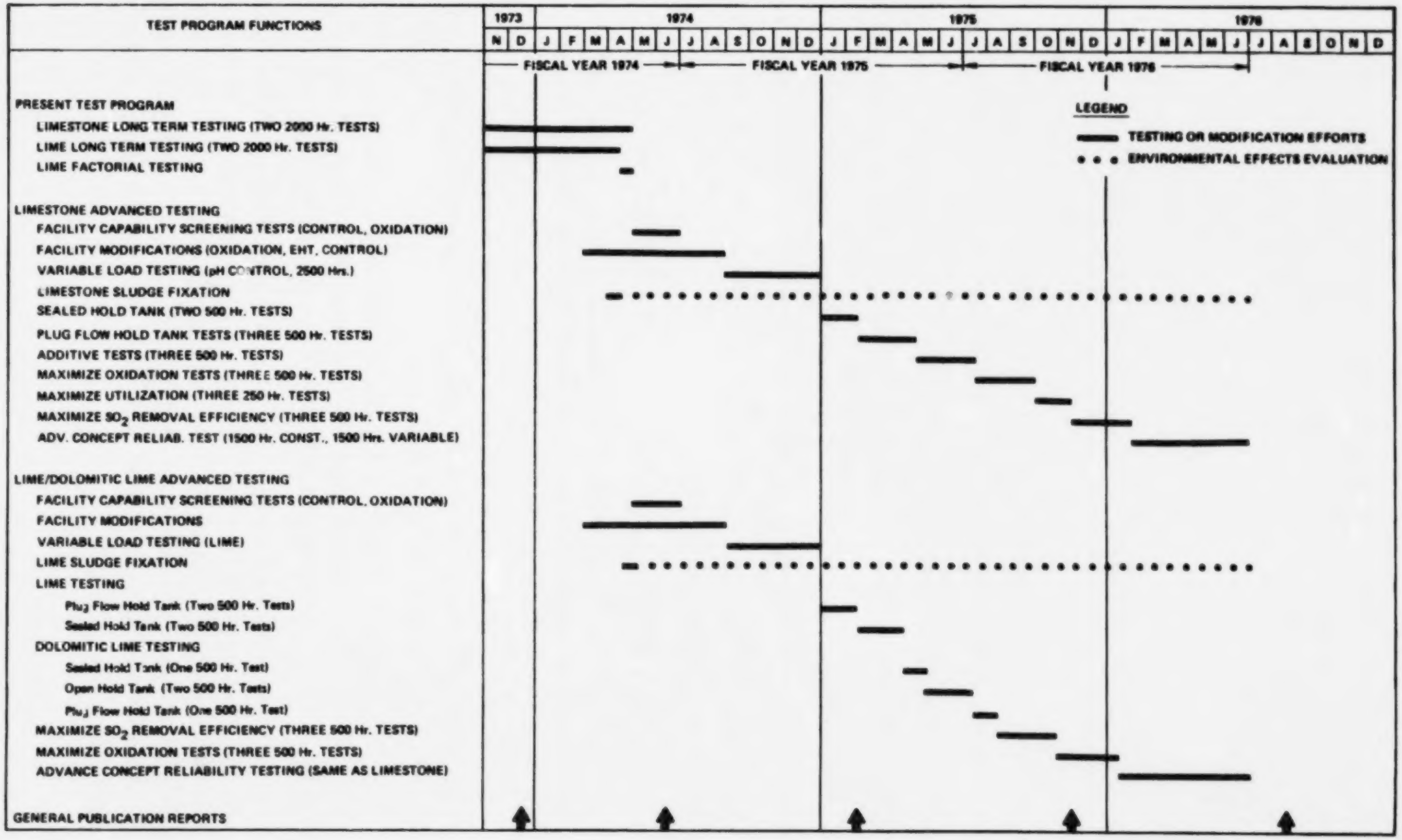

Figure 8-1. Preliminary Schedule for Advanced Shawnee Program

- Investigate process variations and/or dewatering equipment which are capable of producing a more acceptable sludge product.
- Perform long term reliability testing on advanced limestone and lime process variations which offer substantial improvement over present process variations in one or more of the following areas: potential reliability, limestone utilization, SO_2 removal efficiency and improved sludge product characteristics.

In order to attempt to achieve these objectives, the following represents our preliminary thinking regarding the elements of the advanced program:

Limestone Testing

For limestone, based on the results of the present test program, a single scrubber train will be selected for advanced testing; in all probability this will be the Turbulent Contact Absorber. Design of system modifications will be initiated during early 1974 with the aim of supplying a plug flow hold tank and other modifications necessary for future testing. Facility capability screening tests will be the first tests performed following the present test program. These will attempt to evaluate the facility's present capability (without modifications) in terms of (1) supplying the necessary oxidation capability (via air sparging in the present effluent hold tank) to produce an improved gypsum-rich sludge product and (2) ability of the present pH control-system to effectively adjust limestone feed rates to correspond to wide variations in flue gas and inlet SO_2 concentration variations. Approximately two months are planned for the necessary system modifications.

Subsequent to this, variable load testing for a period of approximately 2500 hours will be performed on the process variation subjected to earlier reliability testing. The pH control system selected will attempt to keep the chemistry of the system in balance despite the wide variations in SO_2 inlet concentrations associated with normal Shawnee coal supplies, and a pre-programmed flue gas flow rate daily history (via duct damper settings) which will simulate a widely varying boiler output.

At the conclusion of this test, the effluent hold tank will be sealed and process parameters selected to attempt to operate with the lowest practicable oxidation; this will hopefully enable operation in the "unsaturated-gypsum" mode which has potential for eliminating gypsum scaling as a potential operating problem. After completion of this testing, the plug flow hold tank will be tested as an alternative to the present stirred tank; this configuration offers the following potential advantages: (1) elimination of hold tank oxidation allowing greater potential for unsaturated operation, (2) improved limestone utilization and/or SO_2 removal efficiencies, and (3) potentially improved pH control, since the more sensitive scrubber outlet pH can be used as the limestone feed rate control variable.

In another attempt to increase limestone utilizations and/or SO_2 removal efficiencies, additives will be tested for their ability to increase limestone dissolution rates with corresponding improvements in performance.

Subsequent to this, process variations will be selected which offer the potential for producing sludge with more desirable properties. For example, oxidation of scrubber slurry will be enhanced (via air sparging in a hold tank or by a separate oxidizer utilizing Japanese technology) to produce a predominately gypsum/fly ash product which should have vastly improved settling characteristics over calcium sulfite-rich sludges. Advanced dewatering equipment and liquor bleed stream treatment equipment might also be tested with the aim of producing a more acceptable landfill material without the need for a fixation treatment process.

Based on the results obtained prior to this point, two separate test series will be performed; they will attempt to find conditions associated with achieving maximum limestone utilization (minimum sludge production) and maximum SO_2 removal efficiencies, respectively, consistent with constraints imposed by scrubber type, pressure drop limitations and reasonable process economics.

The last scheduled limestone run would involve long term reliability testing on an advanced process variation selected based on results of prior evaluation and optimization testing. The process variation will be selected with the aim of maximizing reliability, limestone utilization and SO_2 removal efficiency, and improving sludge characteristics consistent with reasonable process economics.

Lime Testing

A single scrubber type will be selected for lime testing; based on results to date this will probably be the venturi/spray absorber. As discussed under limestone testing, facility capability screening tests and system modifications will be performed during mid-1974 with subsequent performance of variable load testing using hydrated lime [$Ca(OH)_2$] as the alkali.

Subsequent testing will be divided into hydrated lime and slightly dolomitic hydrated lime [$Ca(OH)_2 \cdot \sim 5\%\ Mg(OH)_2$] test blocks. This is planned based on the research data generated at the RTP scrubber facility and communications with commercial vendors which indicate that dolomitic lime offers the following potential advantages over low-magnesium lime: (1) higher SO_2 removal efficiency potential due to higher concentration of the sulfite anion in solution, and (2) higher potential for operation in the unsaturated-gypsum mode, since higher concentrations of dissolved sulfates have been shown to favor formation of $CaSO_3/CaSO_4$ solid solutions.

Two series of lime tests are planned which will evaluate sealed stirred tank and plug flow hold tank variations on unsaturated operation and, in the case of the plug flow hold tank, on SO_2 removal efficiencies and lime utilization.

A similar test series will be performed using dolomitic lime as the alkali; however, three effluent hold tank variations will be evaluated: the sealed stirred tank, the plug flow hold tank, and the conventional stirred tank.

Subsequent to this testing, two test series will be performed with the objective of maximizing SO_2 removal efficiencies, and improving sludge characteristics, respectively. These will be similar in scope to the limestone tests described earlier.

Finally, the last lime test would involve long term reliability testing on an advanced lime (or dolomitic lime) process variation, selected as the most promising based on a review of prior testing.

Section 9

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5. A. Saleem, J. Air Pollution Control Assoc., Vol. 22, No. 3, March 1972.

Appendix A

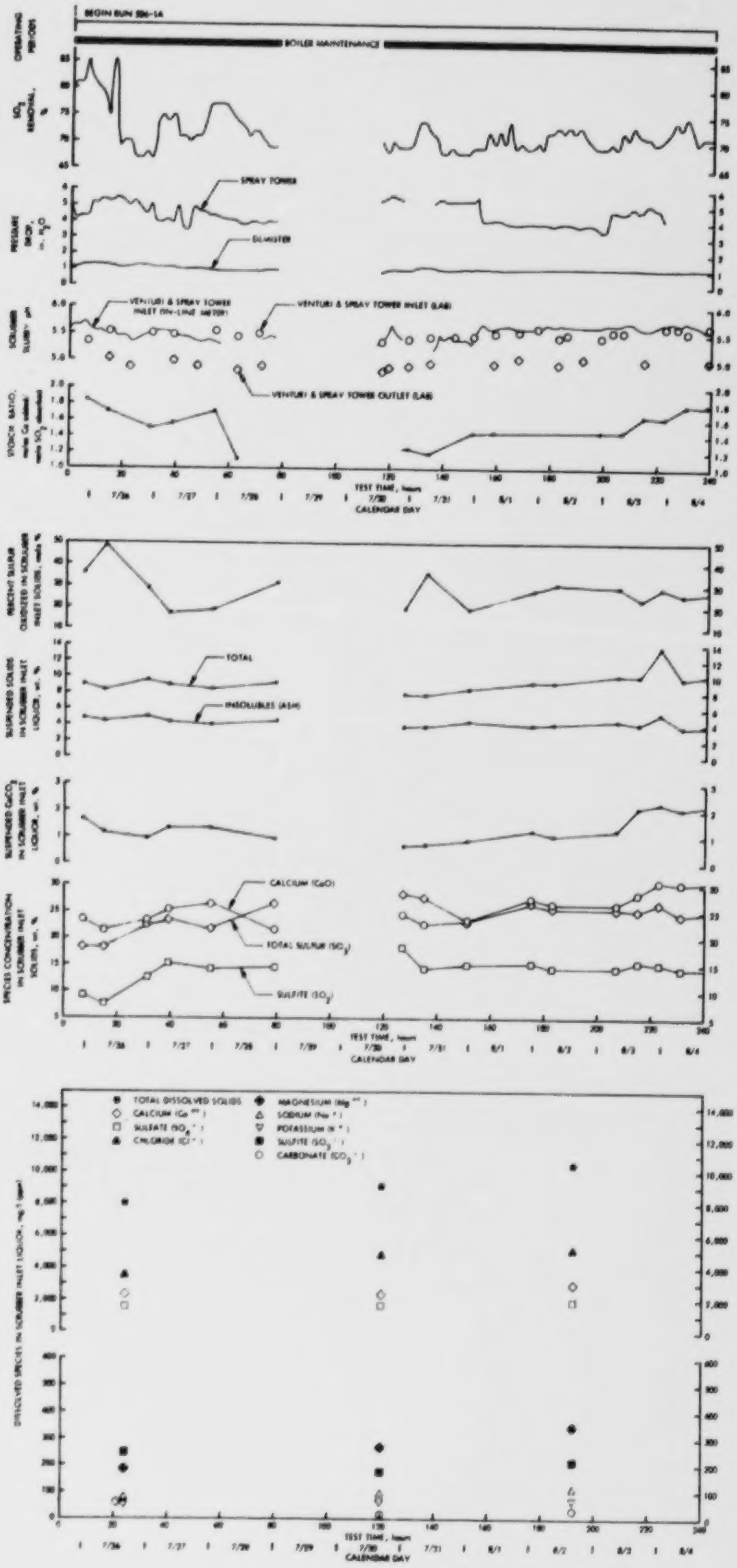
CONVERTING UNITS OF MEASURE

Environmental Protection Agency policy is to express all measurements in metric units. When implementing this practice will result in undue costs or lack of clarity, conversion factors are provided for the non-metric units. Generally, this report uses British units of measure. For conversion to the metric system, use the following conversions:

To Convert From	To	Multiply By
acfm	nm^3/hr	1.70
^oF	^oC	subtract 32 then ÷ 1.8
ft	m	0.305
ft/sec	m/sec	0.305
gal/mcf	ℓ/m^3	0.134
gpm	ℓ/min	3.79
gpm/ft^2	$\ell/\ min/m^2$	40.8
gr/scf	gm/m^3	2.29
in	cm	2.54
in. H_2O	mm Hg	1.87
lb-moles	gm-moles	454
lb-moles/hr	gm-moles/min	7.56
lb-moles/min	gm-moles/sec	7.56

Appendix B

GRAPHICAL OPERATING DATA FROM LIMESTONE RELIABILITY VERIFICATION TESTS



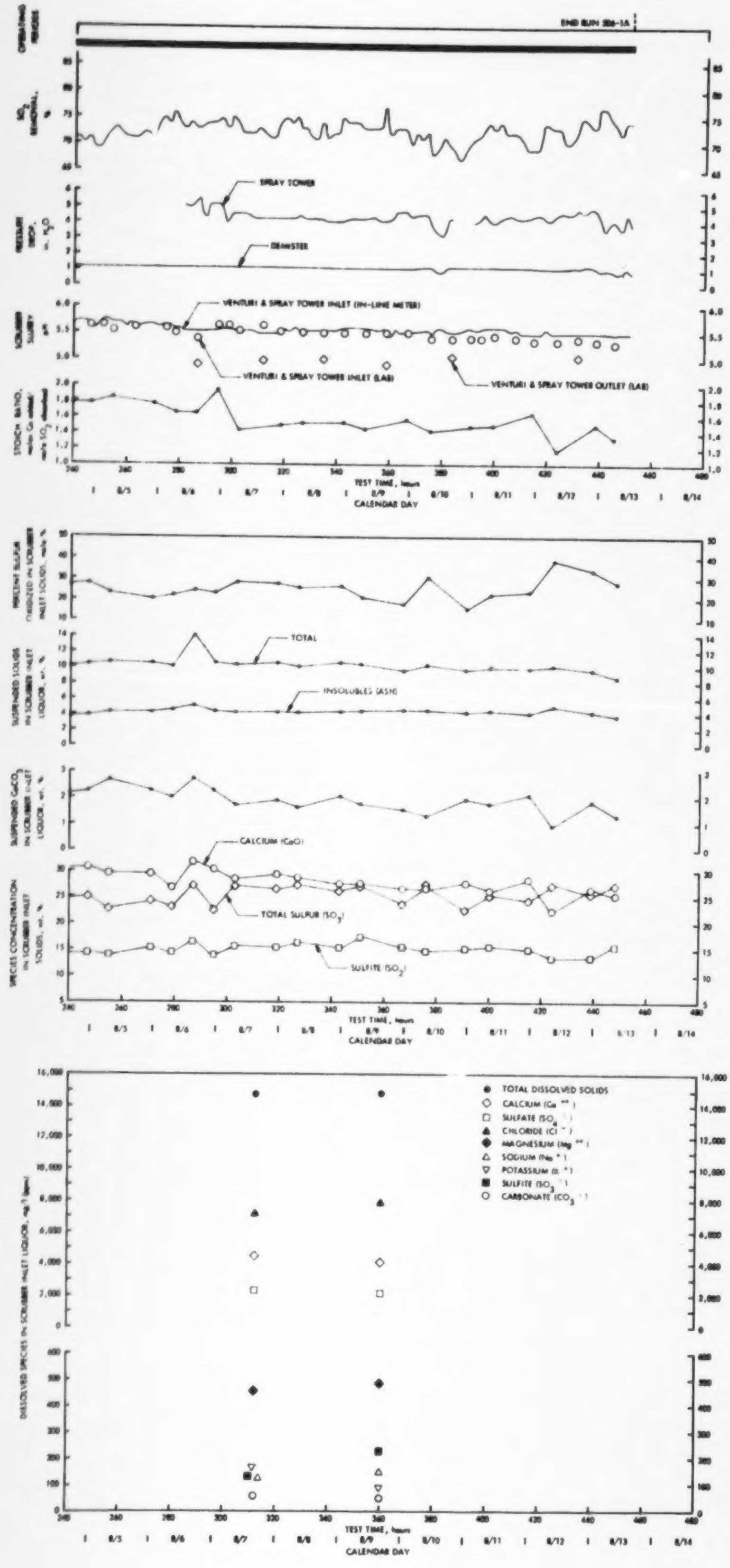
Gas Rate = 30,000 acfm @ 320 °F
Liquor Rate to Venturi = 600 gpm
Liquor Rate to Spray Tower = 1,200 gpm
Venturi L/G = 27 gal/mcf
Spray Tower L/G = 53 gal/mcf
Spray Tower Gas Velocity = 7.5 ft/sec
Venturi Pressure Drop = 9 in H_2O
E.H.T. Residence Time = 12 min
No. of Spray Headers = 4

Gas Inlet SO_2 Conc. = 2,500-3,200 ppm
(2,000-2,200 ppm during 7/26 and 7/28)
Scrubber Inlet Liquor Temp. = 125-131 °F
Liquid Conductivity = 9,500-21,500 μ mhos/cm
Discharge (Clarifier & Centrifuge) Solids
Conc. = 57-65 wt %

Note: As of July 27, a limestone containing approximately 1-1/4 mole % Mg CO_3 has been used at the test facility. Prior to this time a limestone having approximately 5 mole % Mg CO_3 has been used.

Figure B-1

OPERATING DATA FOR VENTURI
RUN 506-1A

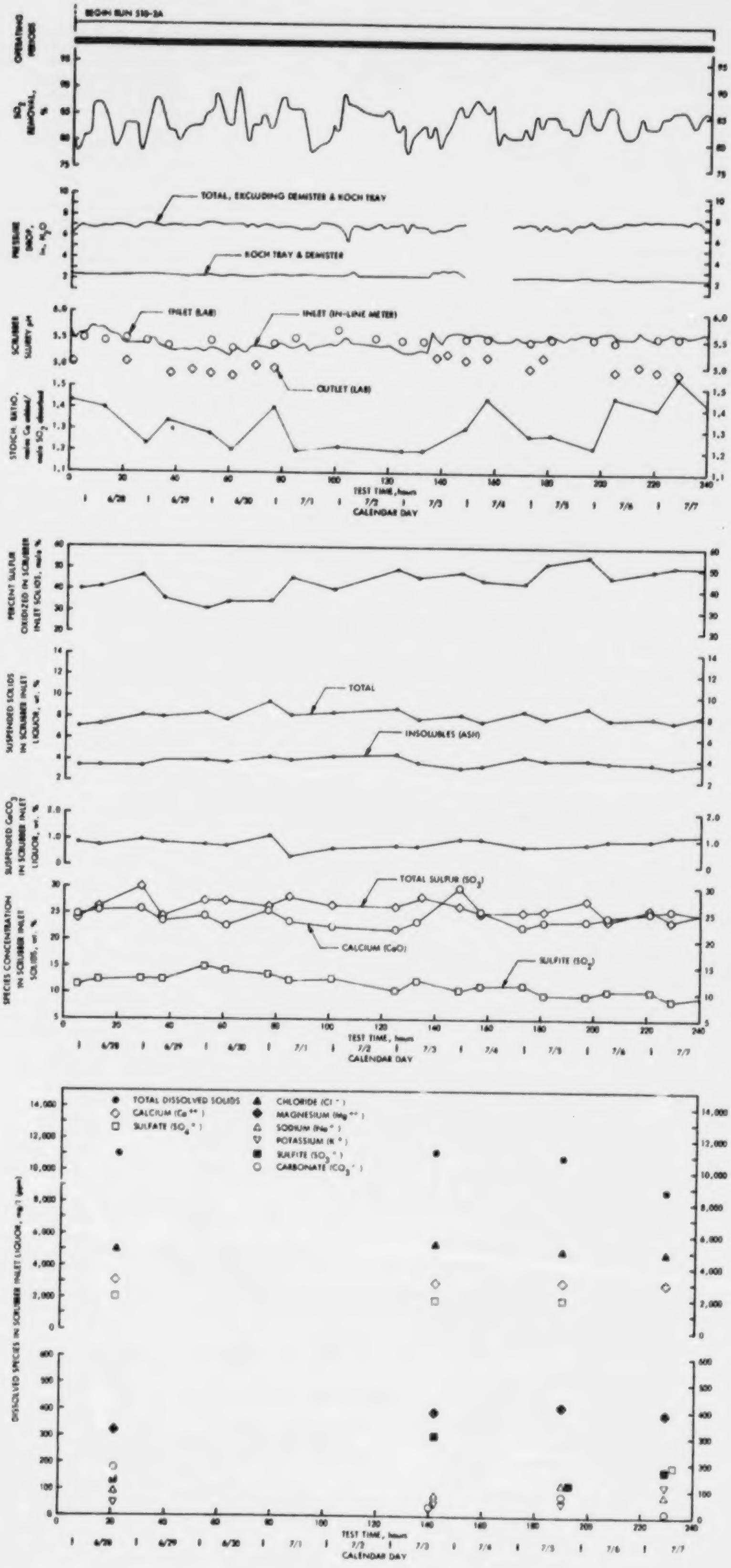


Gas Rate = 30,000 acfm @ 330 °F
Liquor Rate to Venturi = 800 gpm
Liquor Rate to Spray Tower = 1,200 gpm
Venturi L/G = 27 gal/mcf
Spray Tower L/G = 53 gal/mcf
Spray Tower Gas Velocity = 7.5 ft/sec
Venturi Pressure Drop = 9 in H_2O
E.H.T. Residence Time = 12 min
No. of Spray Headers = 4

Gas Inlet SO_2 Conc. = 2,800-3,300 ppm
Scrubber Inlet Liquor Temp. = 128-132 °F
Liquid Conductivity = 22,000-27,000 μ mhos/cm
Discharge (Clarifier & Centrifuge) Solids
  Conc. = 56-66 wt %

Figure B-1 (Continued)

OPERATING DATA FOR VENTURI RUN 506-1A

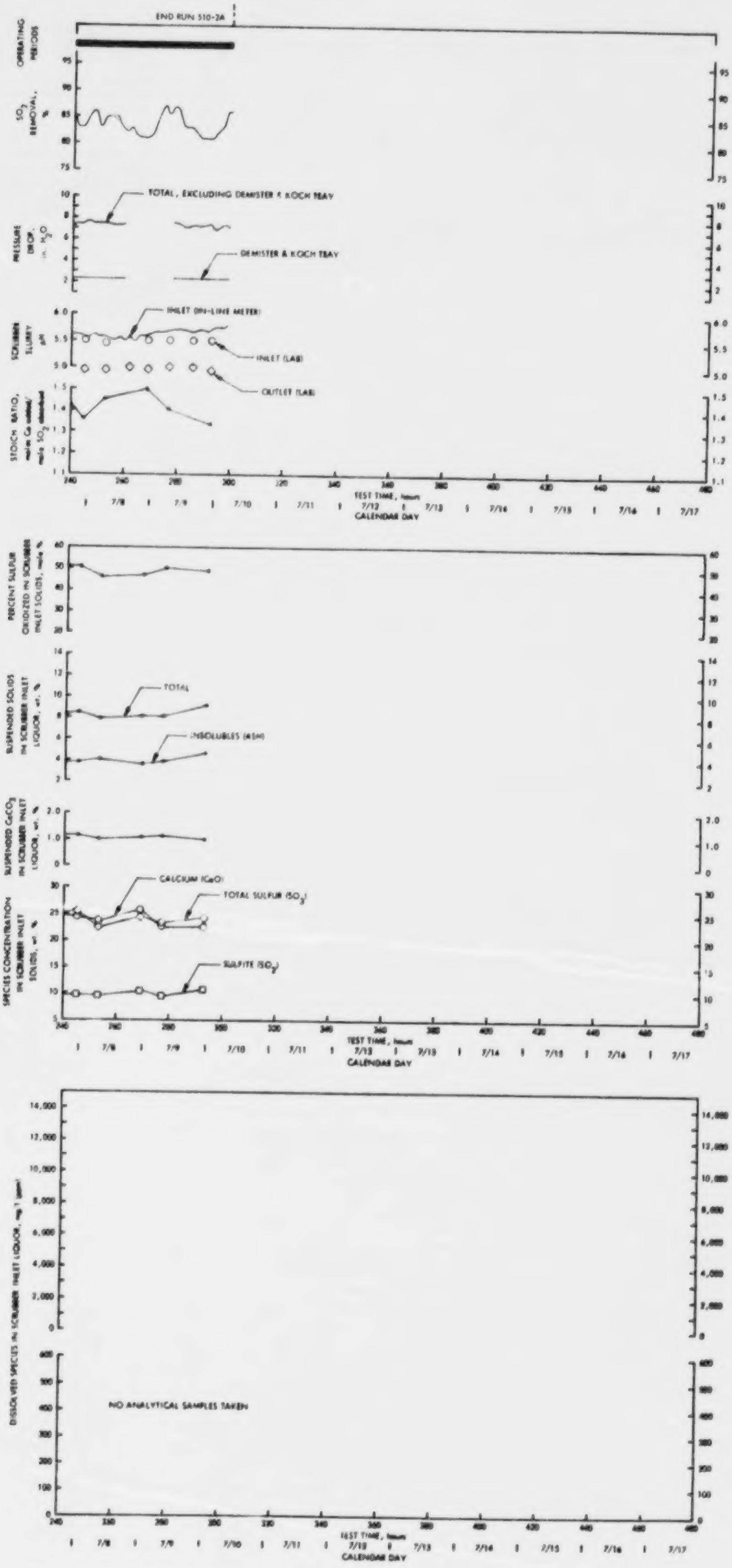


Gas Rate = 25,000 acfm @ 300 °F
Liquor Rate = 1,200 gpm
L/G = 64 gal/mcf
Gas Velocity = 9.8 ft/sec
E.H.T. Residence Time = 20 min
Three Stages, 5 in spheres/stage

Gas Inlet SO_2 Conc. = 2,000-2,700 ppm
Scrubber Inlet Liquor Temp. = 121-127 °F
Liquid Conductivity = 11,000-20,000 μ mhos/cm
Discharge (Clarifier) Solids Conc. = 28-44 wt %

Figure B-2

OPERATING DATA FOR TCA RUN 510-2A

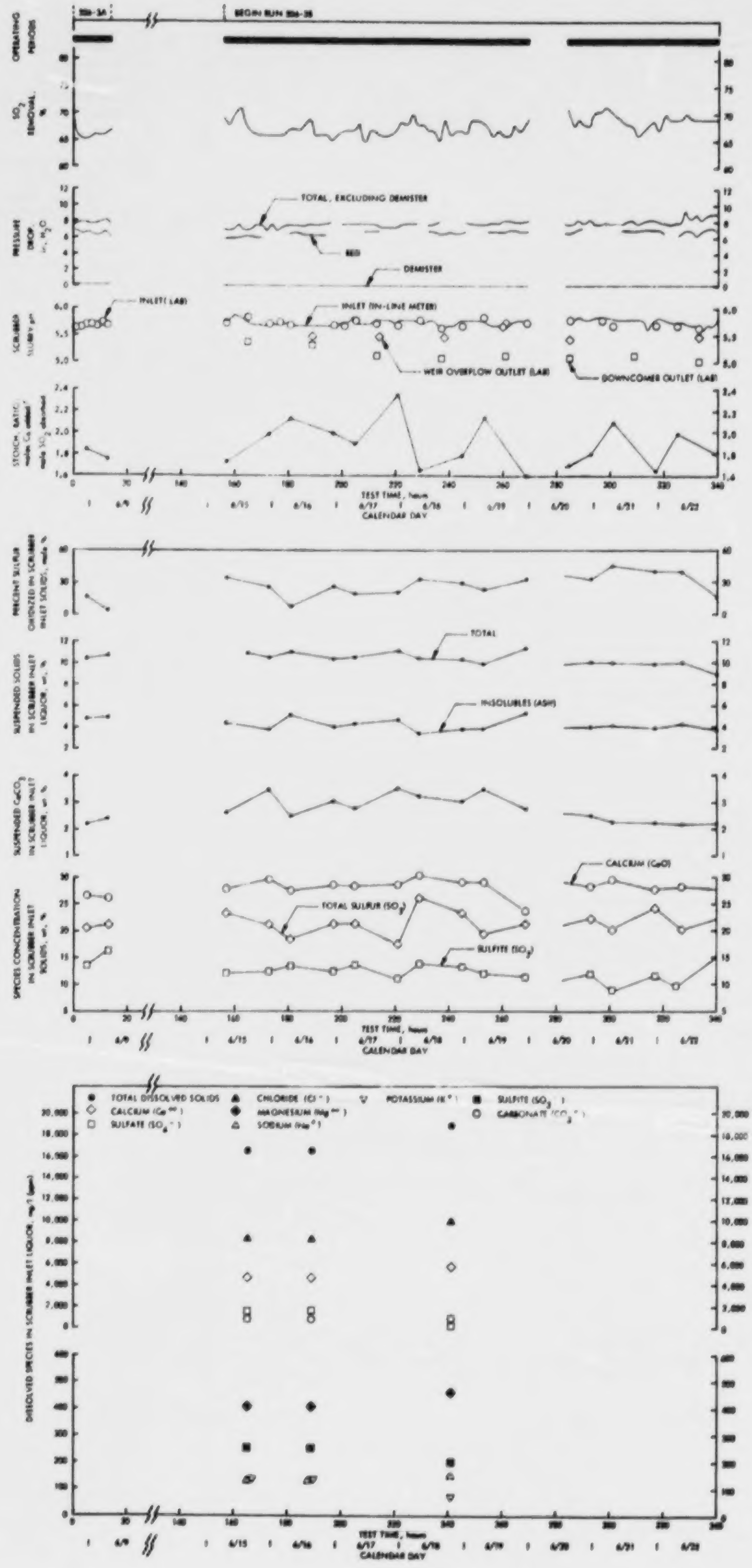


Gas Rate = 25,000 acfm @ 300 °F
Liquor Rate = 1,200 gpm
L/G = 64 gal/mcf
Gas Velocity = 9.8 ft/sec
E.H.T. Residence Time = 20 min
Three Stages, 5 in spheres/stage

Gas Inlet SO_2 Conc. = 2,200-2,800 ppm
Scrubber Inlet Liquor Temp. = 123-127 °F
Liquid Conductivity = 18,000 - 22,400 μ mhos/cm
Discharge (Clarifier) Solids Conc. = 36-39 wt %

Figure B-2 (Continued)

OPERATING DATA FOR TCA RUN 510-2A

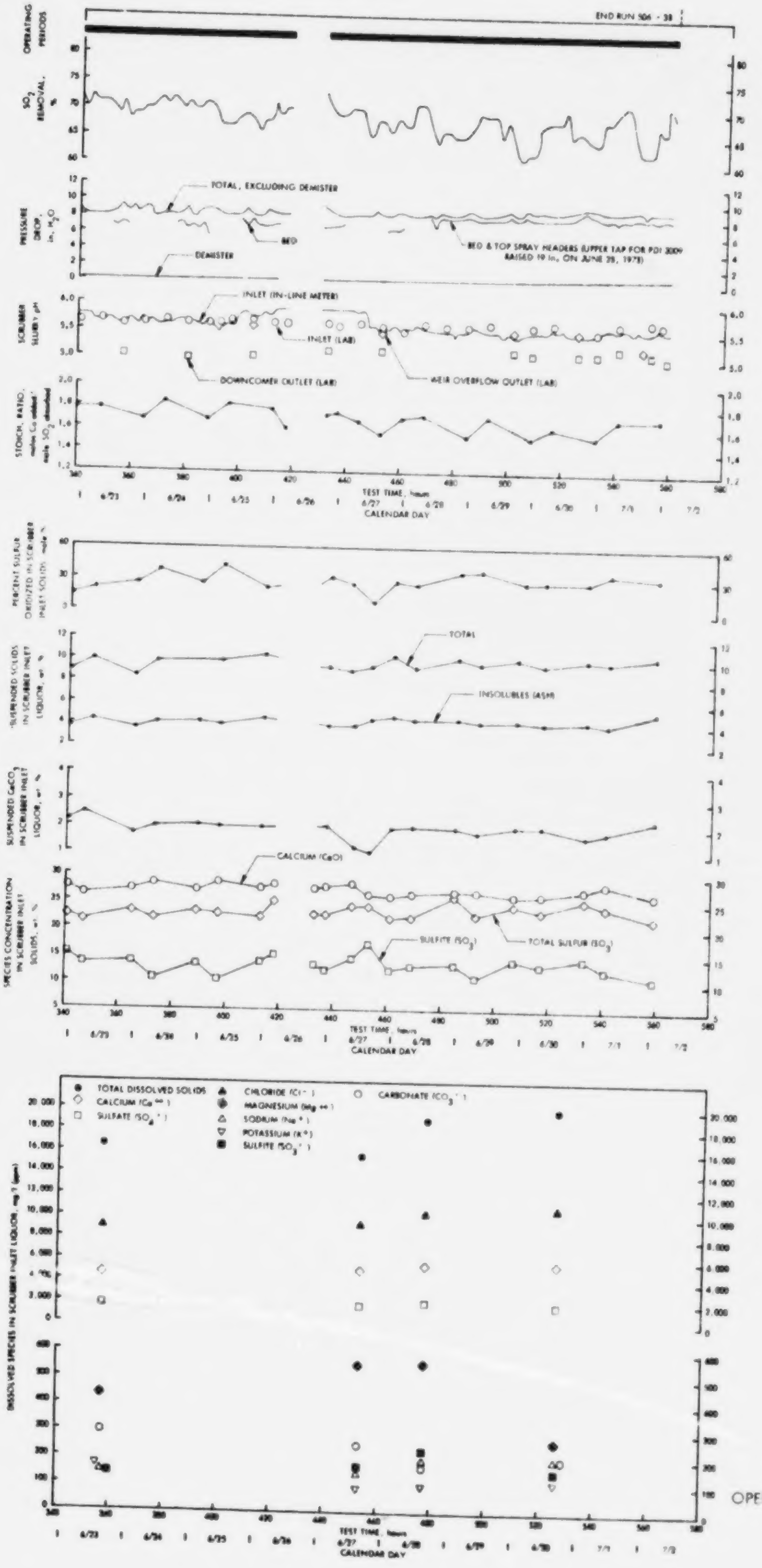


Gas Rate = 20,000 acfm @ 330°F
Liquor Rate = 800 gpm (total)
L/G = 53 gal/mcf
Gas Velocity = 5.1 ft/sec
E.H.T. Residence Time = 20 min
Marble Bed Height = 3.5 in

Gas Inlet SO_2 Conc. = 2,200-3,100 ppm
Scrubber Inlet Liquor Temp. = 122-128 °F
Liquid Conductivity = 33,000-32,000 μ mhos/cm
Discharge (Centrifuge) Solids Conc. = 60-66 wt %

Figure B-3

OPERATING DATA FOR MARBLE-BED
RUN 506-3A & 3B



Gas Rate = 20,000 acfm @ 330°F
Liquor Rate = 800 gpm
L/G = 53 gal/mcf
Gas Velocity = 5.1 ft/sec
E.H.T. Residence Time = 30 min
Marble Bed Height = 3.5 in

Gas Inlet SO_2 Conc. = 2,100-3,200 ppm
Scrubber Inlet Liquor Temp. = 122-130 °F
Liquid Conductivity = 25,000-30,500 μ mhos/cm
Discharge (Centrifuge) Solids Conc. = 60-66 wt %

Figure B-3 (Continued)

OPERATING DATA FOR MARBLE-BED RUN 506-3A & 3B

Appendix C

TEST RUN INSPECTION SUMMARY TABLES

Table C-1

Run No. 501-1A (Depletion Stage) On Stream 16 Hours Operating Date April 9 thru April 10, 1973

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	*	*
Venturi Scrubber	10 mil scale on walls and in flooded elbow.	Negligible	Negligible
Afterscrubber	5 mil intermittent scale in afterscrubber section, on and below trapout tray, on and below demister scrubber at second from bottom slurry header.	Negligible	Negligible
Nozzles (1) Spr. Demister Flush (2)	5 mil scale on fourth (Top) and second slurry header systems and bottom demister spray headers. (SO_3-30.6% wt. CO_2-2.0% wt. SO_2-36.3% wt., Ash-10.0% wt.).	Negligible	Negligible
Chevron Stainless Steel Demister	5 mil scale precipitate on bottom vanes.	Top completely free of solids.	Negligible
Reheater	*	*	*
ID Fan	*	*	*
Miscellaneous	*	*	*

(1) Bete Fog TF 48 FCN
(2) Top - Spraying Systems Co. No. 1 H 7
Bottom - Spraying Systems Co. No. 3/4 H 6 W

*Denotes not applicable or not inspected.

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Table C-2

Run No. 501-1A On Stream 629 Hours Operating Date April 10 thru May 9, 1973

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	3 ft.^{3} flyash accumulation in horizontal section of ductwork upstream of saturation sprays. (Result of 2475 operating hours)	Negligible
Venturi Scrubber	Scattered thin scale precipitate on walls; flooded elbow had 35 mil scale. (SO_3-53.9% wt., CaO-14.7% wt., SO_2-29.6% wt., Ash-1.7% wt.)	Negligible	Guide vane bolts and surrounding area continue to erode; two of eight annealed 316 stainless steel bolts warrant removal.
Afterscrubber	Intermittent scale in afterscrubber section; 25 mil on and below trapout tray; 25 mil at second from bottom header spray area. 15 mil on and below demister (SO_3-57.8% wt., SO_2-15.3% wt., CaO-21.4% wt., Ash-4.9% wt.)	12 ft.^{3} solids deposit on bottom of trapout tray. Scattered 3 inch deep deposits on top slurry and demister bottom wash headers.	Negligible
Nozzles(1) Spr. Demister(2) Flush	25 mil scale on second header nozzles; 15 mil scale on top header nozzles.	Five slurry nozzles totally plugged; four slurry nozzles partially plugged in afterscrubber section.	Slurry afterscrubber nozzles were worn but in good condition.
Chevron Stainless Steel Demister	15 mil scale on bottom vanes; scattered scale deposit on top of vanes (SO_3-66.6% wt., CO_2-50% wt., SO_2-Trace, Ash-25.7% wt.)	Negligible	The 316 stainless steel demister was lightly pitted and corroded with some bent vanes from handling but demister was in good condition. Stainless steel demister was removed and polypropylene demister installed.
Reheater	*	1/8 inch dry solids in duct above reheater; 3 burners cleaned.	Stainless steel sleeve was severely deformed on the north side in teardrop shape, several small cracks at section joints. Refractory had numerous cracks (≤ ¼ inch wide) but was still intact.
Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
ID Fan	*	Thin dry solids film on fan blades	Negligible
Miscellaneous	*	*	*

(1) Bete Fog TF [illegible]8 FCN

(2) Top - Spraying Systems Co. No. 1 H 7

Bottom - Spraying Systems Co. No. 3/[illegible] H 6 W

*Denotes not applicable or not inspected.

Table C-3

Run No. 502-1A On Stream 278 Hours Operating Date June 13 thru June 26, 1973

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	*	*
Venturi Scrubber	5 mil scale on walls; 30 mil scale on walls of flooded elbow. (SO_3-43.6% wt., CO_2-7.9% wt., SO_4-19.3% wt., Ash-6.6% wt.)	Negligible	North and east guide vane cross braces were eroded in arc shapes of 5 inch length, 13/16 inch maximum depth and 5½ inch length, 1 inch maximum depth respectively. The south and west cross braces were eroded to arc shape but less severely. The guide vanes, guide vane bolts, and splash seal nuts and bolts were also significantly eroded. Most of the erosion took place in 923 hours since the February '73 outage.
Afterscrubber	10 mil scale on walls beneath trapout tray	4 ft.^{3} solids deposit on bottom of trapout tray. Scattered ½-2 inch solids deposits on top slurry header and bottom demister wash header.	Negligible
Nozzles Spray$^{(1)}$ Demister Flush$^{(2)}$	Negligible	One plugged slurry nozzle	Afterscrubber slurry nozzles were eroded but still in good condition.
Chevron Polypropylene Demister	1/16 inch scale on top vanes. (SO_3-47.2% wt., SO_4-14.5% wt., CO_2-2.8% wt., CaO-1.6% wt., Ash-33.9% wt.)	Scattered infrequent solids deposits on bottom vanes; about 1/3 ft.^{2} flow area is blocked at four corners at demister support bar junctions.	Negligible
Reheater	*	1/16 inch dry solids in duct above reheater	Stainless steel sleeve continues to deteriorate but at slower rate than in past. Sleeve is severely bulged and warped on the north side with two cracks, each ~6 inches long. Refractory has deteriorated slightly, is severely cracked, but still intact. Burners are oil coated but not damaged or deformed.
ID Fan	*	Thin dust coating on fan blades; fan dampers had no significant solids deposition.	Negligible
Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Miscellaneous	*	*	*

(1) Bete Fog TF 48 FCN
(2) Top - Spraying Systems Co. No. 1/7
Bottom - Spraying Systems Co. No. 3/4 H6W

*Denotes not applicable or not inspected

Table C-4

Run No. 503-1A On Stream 256 Hours Operating Date June 29 thru July 11, 1973

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	*	*
Venturi Scrubber	20 mil scale on walls; 35 mil scale on walls in flooded elbow. (SO_3-79.1% wt., CO_2-2.3% wt., SO_2-0.9% wt., Ash-15.0% wt., CaO-2.6% wt.	Negligible	Erosion on guide vane cross braces continues.
Afterscrubber	15 mil scale on walls beneath trapout tray. Much of scale on wall below demister had dissolved and disappeared, during test 503-1A.	½-1 inch solids deposit on bottom of trapout tray.	Negligible
Nozzles (1)Spray Demister Flush(2)	None	Three slurry spray nozzles were plugged by debris.	Negligible
Chevron Polypropylene Demister	None	Scattered, nonuniform ½-1 inch solids deposits on top of bottom vane and on second vane; four co rner sections were heaviest covered as about 1/3 of their flow area was blocked at'top of bottom vane.	Negligible
Reheater	*	*	*
ID Fan	*	*	*
Miscellaneous	*	*	*

(1) Bete Fog TF 48 FCN
(2) Top - Spraying Systems Co. No. 1 H7
Bottom - Spraying Systems Co. No. 3/4 H6W

*Denotes not applicable or not inspected.

Table C-5

Run No. 504-1A and 505-1A On Stream 23 Hours Operating Date July 11 thru July 12, 1973

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	*	*
Venturi Scrubber	35 mil scale on walls; 30 mil scale on walls of flooded elbow: (SO_3-82.4% wt., CO_2-1.7% wt., SO_2-2.4% wt., Ash-13.3% wt.)	Negligible	Erosion of guide vane cross braces has contined; the maximum depth of the arc shape pattern on the north and east sides have increased to 3/16 and 1/8 inch respectively in 278 operating hours. The south and east guide vane cross braces had not significantly eroded during this time period.
Afterscrubber	30 mil scale on walls beneath trapout tray. Some of scale on walls from previous runs had dissolved and disappeared	0-3/8 inch soft solids on bottom of trapout tray.	Some of 316 stainless steel piping supports were signigicantly pitted but still in good condition.
Nozzles (1)Spray Demister Flush (2)	Negligible	One plugged slurry nozzle in afterscrubber.	Negligible
Chevron Polypropylene Demister	Negligible	½-1 inch solids present on 7/11 are slightly less prevalent on 7/12/73.	Some broken and warped plastic demister vanes, but demister is still in good condition. It has been in place since May 10th inspection; 556 operating hours.
Reheater	*	1/8 inch dry solids deposit in gas duct above reheater.	Three large cracks in stainless steel sleeve (1-2 ft. long, 2-1 ft. long) at section joints. Steel reheater shell showed no discoloration since 6/26/73 (278 hrs.)
ID Fan	*	1-2 inch non-uniform solids deposit on fan inlet dampers.	Negligible
Miscellaneous	*	*	*

(1) Bete Fog TF 48 FCN
(2) Top - Spraying Systems Co. No. 1 H 7
Bottom - Spraying Systems Co. No. 3/4 H 6 W

*Denotes not applicable or not inspected.

Table C-6

Run No. 506-1A On Stream 417 hours Operating Date 7/25/73 - 8/13/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	*	*
Venturi Scrubber	15 mil scale on walls; 15 mil scale on flooded elbow walls.	Small amount of solids under splash seal flange.	Erosion continues on north and east guide vane cross braces, guide vanes, and guide vane nut-bolt assemblies. Erosion continuing on top splash seal flange. Maximum depth of arc shapes on north and east guide vane cross braces had increased 3/32 and 3/16 inches respectively during 417 hours.
After Scrubber	20 mil scale on all 4 slurry spray headers and on bottom half of wall expanse between trapout tray and demister.	Three 4 ft^3 of solids on bottom of trapout tray and on walls adjacent to trapout tray.	Negligible
Nozzles Spray (1) Demisters	20 mil scale on after scrubber slurry nozzles.	3 plugged slurry nozzles in after scrubber.	Negligible
Chevron Polypropylene Demister (a)	5 mil deposit on scrubber walls above demister. SO_3-44.2%WT Ash-27.2%WT SO_2-27.9%WT CO_2- .7%WT	Large solids fell on top from gas duct above.	Large solids deposits (one of 3/4 ft^3) fell on plastic demister from gas duct above and did significant damage. 10% of top vanes were shattered by these solids. Plastic demister was removed and SS demister was installed.
Reheater	*	Several deposits of $\approx$100 in^3 at reheater outlet. $\approx$2 inch solids on gas duct walls above reheater.	Refractory was severely cracked but still intact. Sleeve was distorted badly at north side; cracks between section joints.
ID Fan	*	5 inch solids deposits on bottom of inlet dampers.	Experienced considerable difficulty during test run in controlling gas flow by gas damper positioning and had several shear pin failures on damper linkage between dampers and damper control drive.
Miscellaneous	*	*	Venturi SO_2 outlet probe (AP1020) was partially covered with solids; too extensive a covering on this element could give faulty and useless data.

(a) Used both top and bottom demister flush * Denotes not applicable or not inspected.

(1) Bete Fog TF 48 FCN

(2) Top - Spraying Systems Co. No. 1 H 7
Bottom - Spraying Systems Co. No. 3/4 H 6 W

Table C-7

Run No. 507-1A On Stream 163 Hours Operating Date 8/22/73 - 8/29/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	*	*
Venturi Scrubber	Negligible	$\leq$5 mil solids on walls and flooded elbow.	No additional erosion on guide vane cross braces during this 163 hour period. Some erosion of corrosion specimens and splash seal flange. Haynes 6B and 316 SS test wear bars were installed on top of north and east cross braces.
After Scrubber	Negligible	Negligible	Negligible
Nozzles Spray (1) Demister Flush (2)	Negligible	One slurry nozzle was plugged.	Negligible
Chevron SS Demister	20-40 mil loose crystalline scale on walls above demister.	Light dust coating on top and bottom vanes was $\leq$5 mil thick. Several 2 inch thick small solids deposits fell from gas duct and lay on top.	Negligible
Reheater	*	Carbon deposit in No. 3 burners. Solids in duct above reheater.	Refractory was severely cracked; a 1/2 ft^2 hole has been oxidized in the SS sleeve opposite the No. 2 burner; another 1/2 ft^2 hole next to it due to sleeve joint separation.
ID Fan	*	Negligible	Negligible
Miscellaneous	*	*	*

* Denotes not applicable or not inspected.
(1) Bete Fog TF 48 FCN
(2) Top - Spraying Systems Co. No. 1 H 7
Bottom - Spraying Systems Co. No. 3/4 H 6 W

Table C-8

Run No. 507-1A On Stream 271 Hours Operating Date 8/29/73 - 9/9/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	*	*
Venturi Scrubber	None	3-4 inch solids on Venturi walls around bull nozzle. Small amount (<1/4 inch depth) of solids beneath flange.	Guide vane nut-bolt assembly on inside position on north and east sides was 1/2 eroded. 316 stainless steel test bar on east side shows observable wear; Haynes 6B on north side does not. (test bars have been in service for 271 hours).
After Scrubber	None	Negligible	Negligible
Nozzles Spray (1) Demister Flush (2)		Negligible	Negligible
Chevron SS Demister	Negligible	5 mil solids on bottom vanes. In addition, two, 2 ft^2 sections in the top NE sector were plugged 25% and 75% respectively. 10 mil solids deposit on top vanes.	Negligible
Reheater	*	1/4 inch thick solids in duct above reheater.	Piece of refractory found on top of demister (1" x 2" x 3"). SS Sleeve continues to deform; holes in sleeve are enlarging.
ID Fan	*	3 mil solids on blades; dampers were clean.	Expansion joint above ID fan has one 4 inch crack (long) and several 1/2 inch long cracks.
Miscellaneous	*	*	*

*Denotes not applicable or not inspected.

(1) Bete Fog TF 48 FCN

(2) Top - Spraying Systems Co. No. 1 H 7
Bottom - Spraying Systems Co. No. 3/4 H 6 W

Table C-9

Run No. 508-1A On Stream 28 Hours Operating Date 9/11/73 - 9/12/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	*	*
Venturi Scrubber	*	*	*
After Scrubber	None	2 mil dust coating	Negligible
Nozzles (1) Spray Demister Flush (2)	None	Negligible	Negligible
Chevron SS Demister (a)	None	5 mil solids on scrubber wall above demister. 2 mil solids dust on top vanes. Some of small localized solids present on east side on 9/11/73 have disappeared.	Negligible
ID Fan	*	Some solids on bottom dampers.	*
Reheater	*	2 inch scattered red solids in gas duct above reheater.	*
Miscellaneous	*	*	*

(a) Used top and bottom demister flush.

* Denotes not applicable or not inspected.

(1) Bete Fog TF 48 FCN
(2) Top - Spraying Systems Co. No. 1 H 7
Bottom - Spraying Systems Co. No. 3/4 H 6 W

Table C-10

Run No. 509-1A, 511-1A 520-1A, 532-1A On Stream 80 Hours Operating Date 9/12/73 - 9/16/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct (a)	Negligible	1 inch thick, 6 inch wide band at saturation spray area.	Negligible
Venturi Scrubber (b)	None	Some of solids around bull nozzle of 9/10/73 inspection were gone.	Continued erosion on upper flange of splash seal and its accompanying nut-bolt assemblies. 1/3 of nuts on inside position of north and east guide vane cross braces eroded away. 316 SS wear bar was more severely eroded than Haynes 6B but erosion was more severe on east side than on north side.
After Scrubber	10 mil scale on walls beneath trapout tray.	None	Negligible
Nozzles Spray (1) Demister Flush (2)	None	3 plugged slurry nozzles in after scrubber section.	Negligible
Chevron SS Demister	None	Heavy solids on top and bottom. Top - 3/4 inch solids in NE corner - 1/4 inch in SE - 3/8 inch in SW - 1/2 inch in NW quadrant. Bottom had 1/2-1 inch wedge deposit blocking 50% of flow area on east side, 1/4 inch solids on west side.	Negligible
Reheater	*	1/16 inch solids in duct above reheater. Carbon deposit in burner No. 2.	SS sleeve has 2-1/2 ft^2 holes, one was made by oxidation by No. 2 burner. Refractory cracks up to 2inches wide but not as deep as to reheater shell. New sleeve and refractory is being installe
ID Fan	*	1-1/2 inch (avg) 3 inch (max) solids on bottom of damper blades.	Negligible
Miscellaneous	*	*	*

(a) Saturation sprays (raw water) were used as there was no flow to the Venturi scrubber.
(b) No slurry flow to Venturi scrubber.
* Denotes not applicable or not inspected
(1) Bete Fog TF 48 FCN
(2) Top - Spraying Systems Co. No. 1 H 7, Bottom - Spraying Systems Co. No. 3/4 H 6 W

Table C-11

Run No. 501-2A (Depletion Phase) On Stream Hours 22 Hours Operating Dates 3/22/73 - 3/23/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	1/5 of ventri-rod gas flow area was plugged by 3 ft^3 of solids.	Negligible
TCA Scrubber	5 mil scale precipitate on walls beneath bottom bed. (SO_3-19.7% Wt, SO_2 - 32.9% Wt, Ash - 39.1% Wt).	None	Negligible
Nozzles Spray (1) Cooling (2)	None	None	None
Chevron SS Demister	1-2 mil scale on bottom vanes.	None	Negligible
Reheater	*	None	Refractory and SS sleeve were in very good condition.
ID Fan	*	Light limestone dust on blades.	Negligible
Miscellaneous	*	*	*

(1) Spraco full cone, free flow nozzles, No. 1969.
(2) Ceramic nozzle (5/8 inch opening).

* Denotes not applicable or not inspected.

Table C-12

Run No. 501-2A On Stream Hours 253 Hours (134 since last cleaning ventri-rod) Operating Dates 3/23/73 - 4/6/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	70% of ventri-rod assembly blocked by 5 ft^3 of solids.	Negligible
TCA Scrubber	5 mil iron oxide scale on walls immediately beneath Koch tray.	None	None
Nozzles Spray (1) Cooling (2)	None	None	Negligible
Chevron SS Demister	1/16 inch scale precipitate on bottom vanes.	Negligible	Negligible
Reheater	Negligible	Negligible	SS sleeve had not warped or deformed. Reheater refractory above the burners had cracked and exposed expanded metal retaining grid; refractory was repaired.
ID Fan	None	Light dust coating.	Maximum fan blade deformation from straight line pattern was .167 inch.
Miscellaneous	*	*	*

* Denotes not applicable or not inspected.
(1) Spraco full cone, free flow nozzles, No. 1969.
(2) Ceramic nozzle (5/8 inch opening) 3/23/73 - 3/27/73
Open pipe nipple (1.0 inch opening) 3/27/73 - 4/6/73

Table C-13

Run No. 501-2A

On Stream Hours 92 Hours

Operating Dates 4/7/73 - 4/11/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	60% of ventri-rod flow area was blocked by about 4-1/2 ft^3 solids deposit.	Negligible
TCA Scrubber	Negligible	Negligible	Negligible
Nozzles Spray (1) Cooling (2)	•	•	•
Chevron SS Demister	•	•	•
Reheater	•	•	•
ID Fan	•	•	•
Miscellaneous	•	•	•

(1) Spraco full cone, free flow nozzles, No. 1969
(2) Ceramic nozzle (5/8 inch opening).
• Denotes not applicable or not inspected.

Table C-14

Run No. 501-2A

On Stream Hours 86 Hours

Operating Dates 4/12/73 - 4/16/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	5 ft^3 of solids had blocked 50% of ventri-rod flow area (solid was deposited in 86 hours).	Negligible
TCA Scrubber	Negligible	4 - 5 inch solids deposit on west wall beneath each tray.	The flange of the main steam sparger line inside the scrubber had partially separated. Three of four nut-bolt assemblies required replacement.
Nozzles Spray (1) Cooling (2)	Negligible	Ventri-rod was removed and replaced with the 4 original Bete Fog nozzles (ST 24 FCN). Three of four slurry nozzles were partially plugged.	Ceramic cooling spray nozzle for ventri-rod was found broken.
Chevron SS Demister	Negligible	Negligible	Negligible
Reheater	•	•	•
ID Fan	•	•	•
Miscellaneous	•	•	•

(1) Spraco full cone, free flow nozzles, No. 1969.
(2) Ceramic nozzle (5/8 inch opening).
Denotes not applicable or not inspected.

Table C-15

Run No. 501-2A　　On Stream Hours 127 hours　　Operating Dates 4/17/73 - 4/23/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	4 ft^3 solids deposit upstream of cooling spray nozzles.	Negligible
TCA Scrubber	Negligible	2 - 3 inch slurry solids on the east and west walls beneath Koch tray.	Entire 5 inch middle bed had fallen into the bottom bed due to 2 holes in support grid. Four of six grid sections at this elevation were replaced.
Nozzles Spray (1) Cooling (2)	Negligible	The top cooling spray nozzle, a Bete Fog ST 32 FCN nozzle was plugged. Replaced Bete Fog nozzle with Spraco 7LB nozzle.	Negligible
Chevron SS Demister	Negligible	Negligible	Negligible
Reheater	*	1/3 gallon of carbon was deposited at No. 2 burner. 1/16 inch solids covered duct above reheater.	SS sleeve was still of circular shape and was not deformed. Recently repaired refractory (April 6th) was in excellent condition.
ID Fan	*	Light dust coating on blades.	Negligible
Miscellaneous	*	*	About one dozen collapsed spheres in each bed were replaced

(1) Spraco full cone, free flow nozzles, No. 1969.
(2) Four, Bete Fog ST-28 FCN nozzles.
* Denotes not applicable or not inspected.

Table C-16

Run No. 502-2A　　On Stream Hours 303 hours　　Operating Dates 4/27/73 - 5/10/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	A wedge shaped, 4-1/2 ft^3 solids deposit had accumulated on the bottom of the gas duct upstream of cooling spray.	Negligible
TCA Scrubber	5 mil scale on walls beneath bottom grid.	Scattered 0-3 inch solids accumulation on bottom of Koch tray.	Negligible
Nozzles Spray (1) Cooling (2)	*	North cooling spray nozzle was plugged.	Negligible
Chevron SS Demister	Negligible	Negligible	Negligible
Reheater	*	*	*
IF Fan	*	*	*
Miscellaneous	*	*	G-201 pump shaft seal was repacked.

(1) Spraco full cone, free flow nozzles, No. 1969.
(2) Four, Spraco 7 LB 316 SS nozzles.
* Denotes not applicable or not inspected.

Table C-17

Run No. 502-2A

On Stream Hours 268 Hours

Operating Dates 5/10/73 - 5/21/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	60-70% of gas duct flow area immediately upstream of cooling spray nozzles blocked by 7-1/2 ft^3 of solids.	Negligible
TCA Scrubber	Insignificant localized scaling.	One inch solids deposit on slurry nozzles; no other additional solids.	Grid wires in several areas of the top and bottom bed grids were noticeably eroded during test run; however, no grids were removed.
Nozzles Spray (1) Cooling(2)	Negligible	3 of 4 cooling spray nozzles plugged. 2 south slurry inlet spray nozzles partially plugged.	Negligible
Chevron SS Demister	Negligible Additional Scale.	Bottom vane flow area of west quadrant 50% blocked by solids.	Negligible
Reheater	*	*	*
ID FAN	*	*	*
Miscellaneous	*	*	*

* Denotes not applicable or not inspected.

(1) Spraco full cone, free flow nozzles, No. 1969.

(2) Four, Bete Fog ST-32 FCN nozzles.

Table C-18

Run No. 503-2A - 508-2A

On Stream Hours 163 Hours

Operating Dates 5/22/73 - 5/29/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	5-1/2 ft^3 wedge shape deposit on bottom of gas duct immediately upstream of cooling sprays. NOTE: To prevent solids buildup in the gas duct, the sootblower nozzle and blowing cycle was altered as well as the bottom cooling spray nozzle was capped.	Negligible
TCA Scrubber	Negligible	2 - 3 inch solids on west wall, and 1 inch on east wall, immediately below Koch tray.	Loosening, bending and erosion of grid wires continues. Two grid sections of the bottom bed were replaced; in one, 4 lineal inches of wire were missing.
Nozzles Spray (1) Cooling (2)	Negligible	South cooling spray nozzle and associated header were plugged. Southeast slurry nozzle was partially plugged.	Negligible
Chevron SS Demister	Negligible	Negligible	Negligible
Reheater	Negligible	Negligible	Reheater refractory above burners cracked and exposed expanded metal to flame. Reheater sleeve is still circular and in good condition. Several small section cracks at welds.
ID Fan	*	1 inch solids accumulation on bottom of inlet dampers.	Negligible
Miscellaneous	*	*	≈ 7% of plastic spheres were damaged. North steam sparge header under the Koch tray had vibrated loose from the main header.

(1) Spraco full cone, free flow nozzles, No. 1969.

(2) Four, Bete Fog ST-32 FCN nozzles.

* Denotes not applicable or not inspected.

Table C-19

Run No. 509-2A On Stream Hours 465 Hours Operating Dates 6/5/73 - 6/25/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	Negligible	Negligible
TCA Scrubber	60 mil scale on walls beneath bottom bed. (SO_3-71.6% Wt, SO_2 -2.2% Wt, CaO-5.8% Wt Ash-20.4% Wt) 35 mil scale on walls beneath top and bottom beds.	1/2 ft^2 of scale-solids stalactites on NE corner of bottom grid (SO_3-48.8% Wt, SO_2-9.3% Wt, Ash-41.7% Wt).	Grid wires continue to deteriorate. Five top grid sections had broken wires; 4 grid sections were replaced; one was repaired in place by tackwelding.
Nozzles Spray (1) Cooling (2)	Negligible	North cooling spray nozzle was plugged; all 4 slurry spray nozzles were partially plugged.	Negligible
Chevron SS Demister	1/16 inch scale on bottom and second from bottom vanes (SO_3-67.9% Wt, CaO-0% Wt, SO_2 -2.7% Wt, Ash-28.6% Wt).	Negligible	Negligible
Reheater	*	1/16 inch dry flaky solids above reheater.	Two small cracks (≈3 and 6 inches long) at section joints of SS sleeve. Refractory in excellent condition since its repair during 5/30-6/5 outage. Burner shrouds are in good condition, not oxidized.
ID Fan	Negligible	Light dust coating.	Negligible
Miscellaneous	*	*	SS 20% spheres collapsed or were otherwise damaged.

* Denotes not applicable or not inspected.
(1) Spraco full cone, free flow nozzles, No. 1969.
(2) Three, Bete Fog ST-32 FCN nozzles.

Table C-20

Run No. 510-2A On Stream Hours 297 Hours Operating Dates 6/27/73 - 7/10/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	Negligible	Negligible
TCA Scrubber	30 mil scale on walls beneath bottom grid (SO_3-74.9% Wt, SO_2-1.9% Wt, Ash-22.7% Wt) 20 mil scale on walls above bottom bed.	Negligible	Loose and bent grid wires were discovered on several grids, but grids did not require replacement.
Nozzles Spray (1) Cooling (2)	65 mil scale on slurry nozzles (SO_3-61.9% Wt, CaO-0% Wt, SO_2-10.4% Wt, Ash-25.1% Wt).	Top and south cooling spray nozzles were partially plugged. All 4 slurry nozzles were partially plugged.	All 4 slurry nozzle throats were eroded and contained 1/16 inch grooves; nozzles are still in good condition, however.
Chevron SS Demister	60 mil scale covered bottom vanes (SO_3-75.2% Wt, CaO-0% Wt, SO_2-2.0% Wt, Ash-21.4% Wt)	1/2 inch solids between bottom vanes in SW corner. Other sections partially plugged.	Negligible
Reheater	*	1/8 inch dry solids in gas duct above reheater.	SS sleeve had 5 cracks, only 2 are significant (≈ 4 and 8 inches long); only one small crack above No. 2 burner in refractory.
ID Fan	*	Light dust coating on blades. Nonuniform 1-2 inch solids accumulation on inlet dampers.	Negligible
Miscellaneous	1/3 of the bottom grid was covered with 1/4 inch stalactite scale. (SO_3-91.8% Wt, Ash-9.2% Wt, SO_2-1.8% Wt)	*	*

* Denotes not applicable or not inspected.
(1) Spraco full cone, free flow nozzles, No. 1969.
(2) Three, Bete Fog ST-32 FCN nozzles.

Table C-21

Run No. 511-2A On Stream Hours 15 Hours Operating Dates 7/10/73 - 7/11/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	Negligible	Negligible
TCA Scrubber	5-10 mil scale on bottom of bottom grid. In 15 hour period 50% of grid was scaled. Previous stalactite scale had increased in length .05inch (SO_3-77% Wt, SO_4-2.17% Wt, CO_3-3.2% Wt, Ash-17.7% Wt present composition) 0.3 inch scattered scale was more densely populated on east and north walls than on 7/10/73.	*	Negligible
Nozzles Spray (1) Cooling (2)	Negligible	Negligible	Negligible
Chevron SS Demister	*	*	*
Reheater	*	*	*
ID Fan	*	*	*
Miscellaneous	*	*	*

* Denotes not applicable or not inspected.

(1) Spraco full cone, free flow nozzles, No. 1969.
(2) Three, Bete Fog ST-32 FCN nozzles.

Table C-22

Run No. 511-2A, 512-2A, 513-2A On Stream 20 Hours Operating Date July 11 thru July 12, 1973

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	Negligible	Negligible
TCA Scrubber	15 mil scale on walls beneath bottom bed. The 5-10 mil scale on 50% of the bottom grid on July 11 had disappeared.	3/16 inch soft solids on valve rims on bottom of Koch tray. $\frac{1}{4}$ inch solids on west wall beneath Koch tray.	Five grid sections were replaced due to loose and/or bent wires. One lineal inch of wire was missing from the west central section of the bottom grid.
Nozzles (1) Spray (2) Cooling	*	North cooling spray nozzle partially plugged.	Cooling spray nozzles (ST-32 FCN) have eroded significantly after 1340 hours operation, but are still quite operative.
Chevron Stainless Steel Demister	*	Additional $\frac{1}{4}$ inch solids on bottom vanes in southwest corner; remainder had 1/8 inch additional solids buildup.	Negligible
Reheater	*	*	*
ID Fan	*	*	*
Miscellaneous	*	Top of Koch tray had <5 mil solids deposit even with no irrigation water during 6½ hours of tests 512-2A and 513-2A.	

*Denotes not applicable or not inspected.

(1) Spraco full cone, free flow nozzles, No. 1969.
(2) Three, Bete Fog ST-32 FCN nozzles.

Table C-23

Run No. 514-2A   On Stream Hours 493 Hours   Operating Dates 7/22/73 - 8/13/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	7 Ft^3 deposit at elbow on bottom of duct.	Negligible
TCA Scrubber	3 mil scale below bottom bed. 30 mil scale between second and third beds. 60 mil scale between top bed and Koch tray.	4 inch solids on west wall beneath Koch tray. Bottom of Koch tray was clean except for 2 ft^2 in SW corner.	Two grid sections were replaced because of broken wires. Several other sections contained loose and bent wires.
Nozzles Spray$^{(1)}$ Cooling$^{(2)}$	*	Top cooling spray nozzle was plugged.	Cooling spray nozzles (ST-32 FCN) are eroded but still in good operating condition.
Chevron SS Demister	45 20% of flow area was plugged by 1/8 inch (avg.) scale on bottom two vanes. (SO$_3$-50.9% Wt, SO$_2$-0.4% Wt, Ash-48.7% Wt)	Negligible	Continued corrosion of vanes (particularly topmost vanes).
Reheater	*	Carbon deposit in No. 3 burner. Light solids in duct above reheater.	SS sleeve is deforming on northeast side. Eight cracks at section joints of sleeve - only 3 over 6 inches; several 1/4 inch wide vertical cracks in refractory.
ID Fan	*	Negligible	Negligible
Miscellaneous	7% of bottom grid was covered with varying scale-solids deposits; some areas were covered with as much as 3/4 and 1 inch stalactites. (SO$_3$-71.7% Wt, SO$_2$-3.4% Wt, CaO-24.3% Wt, Ash-0% Wt).	*	14% of spheres of bottom two beds were punctured or dimpled. All of high density polyethylene spheres in top bed (milky white) were in good condition after 493 hours. G-203 pump shaft sleeve was grooved and required replacement.

* Denotes not applicable or not inspected.

(1) Spraco full cone, free flow nozzles, No. 1969

(2) Three, Bete Fog ST-32 FCN nozzles.

Table C-24

Run No. 515-2A On Stream 571 Hours Operating Date August 16 thru September 10, 1973

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	Solids on TE-2007; remainder of solids in gas duct inlet were negligible.	Negligible
TCA Scrubber Scattered	New .188" scale uniformly covered the walls beneath bottom bed. New scale between bottom bed and Koch tray avg. .062 inch. 2-3 inch stalactite scale on bottom grid. Scattered non-uniform scale-solids of 1 inch max. depth. (Particularly on west side)		1-6 in.² and 2-4 in.² holes in wire grid sections of third grid. Spheres from top bed had fallen into middle bed. Second grid had two lineal inches of wire missing. Four of five steam sparge branch headers and main head flange were loose.
Nozzles (1) Spray (2) Cooling	Negligible	Top and south cooling spray nozzles were plugged. Three slurry spray nozzles were partially plugged.	Erosive grooves in slurry spray nozzle throats were 11 inch deep (max.); nozzles were otherwise in good condition.
Chevron Stainless Steel Demister	~40% of gas flow area at bottom two vanes was blocked by scale and solids. Small scale strip about three inches wide above demister. (SO_3-80.3% wt., SO_4-1.9% wt., Ash-17.8% wt)		Negligible

(1) Spraco full cone, free flow nozzles, No. 1969.
(2) Three, Bete Fog ST-32 FCN nozzles.

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Reheater	*	1/4 and 1/8 inch solids in gas duct entering and leaving reheater, respectively.	Stainless steel sleeve was distorted; new sleeve will be installed. 1/4 inch vertical cracks in refractory.
ID Fan	*	Non-uniform 3 inch deep (max.) solids on bottom of dampers. 5 mil dry dust on back of blades.	Negligible
Miscellaneous	*	*	G-201 pump impeller and inner casing were eroded and pitted to various depths of .200, .275, .300 inches at impeller rim, hub and at suction inlet respectively. G-206 pump inner casing was loose. G-203 and G-205 pump sleeves grooved.

*Denotes not applicable or not inspected.

Table C-25

Run No. 501-3A (Depletion Phase) On Stream Hours 34 Hours Operating Dates 3/14/73 - 3/15/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	Negligible	Negligible
Marble Bed Scrubber	5 mil scale on slurry piping and walls. (74.5%-SO_2 Wt) (10.5%-SO_3 Wt)	Negligible	Negligible
Nozzles Slurry(1) Cooling(2)	*	*	*
Chevron SS Demister	5 mil scale on bottom vanes. No scale on top vanes.	Negligible	Negligible
Reheater	Negligible	Small amount of moisture and solids. (H_2O - 50.7% Wt) (HC - 35.0% Wt) (Ash - 14.3% Wt)	Negligible
ID Fan	*	1/16 inch solids accumulation on back of blades. No appreciable solids on inlet dampers or duct.	*
Miscellaneous	*	*	*

* Denotes not applicable or not inspected.
(1) Bottom header - CE new improved nozzles
Top Header - CE new improved nozzles
(2) Bete Fog ST-20FCN nozzles (four)

Table C-26

Run No. 501-3A On Stream Hours 158 Hours Operating Dates 3/16/73 - 3/23/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	1 ft^3 of solids on north side.	Negligible
Marble Bed Scrubber	Bottom slurry headers and nozzles covered with 3/8 inch scale - solids (Ash-60.1% Wt, SO_3 - 22.7% Wt, SO_2 - 11.1% Wt).		Negligible
Nozzles Slurry(1) Cooling(2)	Bottom slurry spray nozzles covered with 3/8 inch scale - solids (Ash - 60.1% Wt, SO_3 - 22.7% Wt, SO_2 - 11.1% Wt).		The cooling spray header and three of four spray nozzles were obstructed by small pieces of wood and scale. Two of the bottom slurry nozzles were plugged.
Chevron SS Demister	Negligible	1/8 inch slurry deposit on bottom vanes. Light dust covering on top vanes.	Negligible
Reheater	Negligible	0 - 1/4 inch dry solids in outlet duct above reheater.	Negligible
ID Fan	*	Light solids coating.	Two of eight fan blades were significantly warped. One blade had a maximum deformation of 0.56 inches from a straight line pattern.
Miscellaneous	*	*	*

* Denotes not applicable or not inspected.
(1) Bottom Header - CE new improved nozzles.
Top Header - CE new improved nozzles.
(2) Bete Fog ST-20FCN nozzles (Four).

Table C-27

Run No. 501-3B On Stream Hours 26 Hours Operating Dates 3/30/73 - 3/31/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	Small solids deposits on the north and south sides (< 1/2 ft^3).	Negligible
Marble Bed Scrubber	10 mil scale on walls, slurry headers, and slurry nozzles (SO_3 - 60.0% Wt, SO_2 - 24.3% Wt, Ash - 9.3% Wt).	Negligible	Negligible
Nozzles Slurry(1) Cooling(2)	10 mil scale on the top and bottom outer surfaces of the slurry headers.	*	*
Chevron SS Demister	1/10 inch solids-scale accumulation on bottom vanes (see scale analysis above). 1/16 inch soft flaky solids on top vanes.		Negligible
Reheater	*	*	SS sleeve has deformed and distorted slightly but otherwise in good condition.
ID Fan	*	Light Dust Coating.	No further deformation observed or measured.
Miscellaneous	*	*	*

* Denotes not applicable or not inspected.
(1) Bottom Header - CE new improved nozzles.
Top Header - CE new improved nozzles.
(2) Bete Fog ST-20FCN nozzles (Four).

Table C-28

Run No. 501-3B On Stream Hours 83 Hours Operating Dates 4/2/73 - 4/6/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	1 ft^3 (total) solids deposit on north and south side.	Negligible
Marble Bed Scrubber	Negligible	Negligible	Negligible
Nozzles Slurry(1) Cooling(2)	*	*	*
Chevron SS Demister	1/16 inch scale on top vanes. (Ash - 50.2% Wt, SO_3 - 44.0% Wt, SO_2 - 5.1% Wt).	Negligible	Negligible
Reheater	*	Negligible	SS sleeve has warped and deformed to an elongated oval shape. Refractory deterioration rate increasing. Presently has significant number and size of cracks.
ID Fan	*	Thin dust coating.	Negligible
Miscellaneous	*	*	*

* Denotes not applicable or not inspected.
(1) Bottom Header - CE new improved nozzles.
Top Header - CE new improved nozzles.
(2) Bete Fog ST-20FCN nozzles (Four).

Table C-29

Run No. 501-3B On Stream Hours 390 Hours Operating Dates 4/6/73 - 4/22/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	2 ft^3 of slurry-ash soft solids on north and south sides.	Negligible
Marble Bed Scrubber	10 mil scale after 26 hours; 5 mil additional scale after 473 hours.	≈ 12 ft^3 of scale-solids removed from slurry piping, nozzles, bottom of bed and walls.	29% of Marble bed was plugged or in stratified pattern (initial plugging stage).
Nozzles Slurry(1) Cooling(2)	Up to 1 inch of scale-solids on slurry piping and nozzles. (Ash-44.4% Wt, SO_2 - 14.7% Wt, SO_3 - 27.8% Wt, CaO - 12.6% Wt).		The swirl vanes in 13 of the 16 bottom slurry nozzles have completely disappeared, the remaining 3 were only remnants of their original size and shape after 764 hours operation. The 6 top nozzles were only lightly eroded.
Chevron SS Demister	Top had 1/16 inch nonuniform scale and solids accumulation.	Bottom covered with 1/8 inch slurry solids.	Negligible
Reheater	*	1/16 inch of dry soot and solids in duct above reheater. Burners were cleaned.	Refractory continues to crack. SS sleeve continues to deform on north side; currently has "teardrop" shape.
ID Fan	*	Thin soot and solids coating.	No further blade deformation.
Miscellaneous	*		From random samples in the glass sphere bed, the average sphere weight loss during this test was about 6%.

* Denotes not applicable or not inspected.
(1) Bottom Header - CE new improved nozzles.
Top Header - CE new improved nozzles.
(2) Bete Fog ST-20FCN nozzles (Four).

Table C-30

Run No. 502-3A On Stream Hours 285 hours Operating Dates 4/25/73 - 5/7/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	About 6 ft^3 of solids blocked 60-70% of the duct immediately downstream of cooling sprays.	Negligible
Marble Bed Scrubber	5 mil scale beneath bed; (not on walls) 10 mil scale above bed on piping walls, nozzles. (SO_3-56.5% wt, CO_2-7.0% wt, SO_4-24.1% wt, Ash-6.6% wt).	See miscellaneous below.	Negligible
Nozzles Slurry(1) Cooling(2)	5 mil scale on nozzles below bed, 10 mil scale on nozzles above bed.	Negligible	All 16 bottom slurry nozzles are without swirl vanes; remnants of the three vanes on 4/23/73 are now gone. All 6 top slurry nozzle swirl vanes are in good condition.
Chevron SS Demister	Bottom vanes covered with 10 mil scale. Top vanes covered with 1/4 solids and brown scale. (SO_3-55.3% wt, CO_2-4.0% wt, SO_4-6.9% wt, Ash-33.7% wt).	Soft solids from 1/4 - 1/2 inch depth were on scrubber walls above demister.	Negligible
Reheater	Negligible	1/16 inch dry solids accumulation immediately above reheater(H_2O-10.3% wt, Ash-40.2% wt, SO-42.2% wt, H_2SO_4-7.4% wt).	Little change in reheater refractory condition. SS sleeve in "teardrop" shape but no cracks or holes as of present time.
ID Fan	Negligible	Thin-moisture-solids film coating.	No further deformation of fan blades.
Miscellaneous		60% of bed was in stratified pattern with unusually large amount of solids on the marbles but only 2% (1 ft^2) was plugged.	Small hole in SS expansion joint above ID fan. pH of leaking liquid .4. This hole was repaired during outage.

* Denotes not applicable or not inspected.

(1) Bottom Header - CE new improved nozzles.
Top Header - CE new improved nozzles.
(2) Bete Fog ST-24FCN Nozzles (four).

Table C-31

Run No. 503-3A On Stream Hours 267 hours Operating Dates 5/11/73 - 5/22/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	1-1/2 ft^3 of solids on north side and south side.	Negligible
Marble Bed Scrubber	Bottom slurry headers and nozzles and west wall under the bed were covered with 1/2 - 1 inch scale solids deposits. (SO$_3$-38.2% Wt, CaO-30% Wt, SO$_2$-15.9% Wt, Ash-20.3% Wt).		Bed retaining grid was further secured in 4 areas.
Nozzles Slurry$^{(1)}$ Cooling$^{(2)}$	Slurry nozzles covered with 1/2 - 1 inch slurry scale deposits.	North and south most cooling spray nozzles were partially plugged. 3 of 16 bottom slurry nozzles were plugged. C-E nozzles removed, Spraco 8M nozzles installed.	Cooling spray nozzles in good condition. Swirl vanes in top slurry spray nozzles (Combustion Engineering) still intact.
Chevron SS Demister	None	Bottom covered with light dust coating. Top of top vanes covered with 1/8 inch soft solids deposit.	Negligible
Reheater	None	1/8 inch solids deposit in duct above reheater (Ash-21.3% wt, H$_2$O-11.7% wt HC-67% wt).	SS sleeve continues to warp and refractory to crack but at slower rate than in past.
ID Fan	*	1-2 inch solids deposit on bottom of damper blades. Thin solids-moisture coating on fan blades.	No further fan blade deformation.
Miscellaneous	*	Marble Bed was plugged in stratified row pattern over 25% of its area. Stratified areas varied in severity of plugging.	The outer casing rubber liner of G-304 pump was severely eroded and pitted around the suction inlet (up to 1/4 inch deep) due to a piece of slurry nozzle being lodged in the suction line next to the impeller. Two thrust bearings and one inboard had normally wore out and were replaced.

* Denotes not applicable or not inspected.

(1) Bottom Header - CE new improved nozzles.
Top Header - CE new improved nozzles.
(2) Bete Fog ST-20FCN nozzles (four).

Table C-32

Run No. 504-3A and 505-3A On Stream Hours 234 Hours Operating Dates 5/25/73 - 6/4/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	15 mil iron oxide scale.	3-5 ft^3 flyash accumulation upstream of cooling sprays (deposit of 3752 hours operation) 1 ft^3 of solids downstream of cooling sprays.	15 mil iron oxide scale buildup during 3752 operating hours.
Marble Bed Scrubber	Slurry piping under the bed was covered with avg. 1/8 inch slurry-scale deposit. (SO$_3$-43.3% Wt, CaO - 37.5% Wt, SO$_2$ - 7.3%, Ash 7.8% Wt). 5 mil scale on piping and walls above bed during this period.		Negligible
Nozzles Slurry$^{(1)}$ Cooling$^{(2)}$	1/8 inch slurry-scale deposit	6 of 16 bottom slurry nozzles were partially plugged by glass spheres. All top nozzles clean.	None of the Spraco 8 M nozzles had eroded or deteriorated during this period. Four, 16 inch long, 1/2 inch diameter nipples were added to ST-24 FCN nozzles in an attempt to keep inlet gas duct solids deposits at a minimum.
Chevron SS Demister	50-60 mil scale on demister top and on scrubber walls above demister (SO$_3$-70% Wt, CaO-11.9% Wt, SO$_2$ -.8% Wt, Ash - 6.8% Wt).	Light solids on bottom.	Negligible
Reheater	*	Negligible	Reheater refractory is badly cracked but still intact. SS sleeve has warped but has no cracks. No. 2 burner shroud has oxidized significantly.
ID Fan	*	Light solids coating. Non-uniform, scattered 1 inch solids on bottom of inlet dampers.	The small hole in the SW corner of the expansion joint above the ID fan that was repaired at the end of test 502-3A, 500 operating hours earlier, needs repairing again.
Miscellaneous	*	6 ft^2 (12%) of marble bed was plugged. Another 60% of bed is in stratified row pattern.	

*Denotes not applicable or not inspected.

(1) Bottom Header - Spraco 8M nozzles.
Top Header - Spraco 8M nozzles.
(2) Bete Fog ST-20FCN nozzles (Four).

Table C-33

Run No. 506-3A On Stream Hours 14 Hours Operating Dates 6/8/73 - 6/9/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	*	None	Negligible
Marble Bed Scrubber	Negligible	Negligible	Negligible
Nozzles Slurry(1) Cooling(2)	*	3 cooling spray nozzles were completely plugged; remaining one was partially plugged.	The spray of 6 of the 16 bottom slurry nozzles on west and east sides of scrubber was deflected by overflow weir downcomer piping. These nozzles were extended 10-1/2 inches toward the bed. Cooling spray system was modified with 3-7 inch long, 1 inch diameter nipples and ST-32 FCN nozzles.
Chevron SS Demister	Negligible	Negligible	Negligible
Reheater	*	*	*
ID Fan	*	*	*
Miscellaneous	*	50% of Marble Bed was in stratified row pattern. (Incipient plugging stage).	*

* Denotes not applicable or not inspected.
(1) Bottom Header - Spraco 8M nozzles.
Top Header - Spraco 8M nozzles.
(2) Four Bete Fog ST-20FCN nozzles.

Table C-34

Run No. 506-3B On Stream Hours 115 Hours Operating Dates 6/15/73 - 6/19/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	1 ft^3 of slurry solids downstream of the cooling sprays.	Negligible
Marble Bed Scrubber	1/8 inch scale-slurry solids on slurry piping below bed. Walls below and above bed had 10 mil and 5-10 mil scale deposits, respectively.		*
Nozzles Slurry(1) Cooling(2)	*	North and middle cooling spray nozzles were plugged. South nozzle was open.	*
Chevron SS Demister	*	*	*
Reheater	*	*	Part of propane gas supply piping was cracked and propane fuel adjusting screw was inoperative; could not relight reheater.
ID Fan	*	*	*
Miscellaneous	*	1 ft^2 of marble bed was plugged. 12-14% was in stratified row pattern.	*

* Denotes not applicable or not inspected.
(1) Bottom Header - Spraco 8M nozzles.
Top Header - Spraco 8M nozzles.
(2) Three Bete Fog ST-32FCN nozzles.

Table C-35

Run No. 506-3B On Stream Hours 130 Hours Operating Dates 6/26/73 - 7/2/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	4 ft^3 solids deposit on north and south sides downstream of the cooling sprays	Negligible
Marble Bed Scrubber	3/8 inch average scale-solids deposit on slurry piping beneath bed (SO_3-67.2% wt, SO_2-5.5% wt, CaO-2.6% wt, ash-22.7% wt); 50 and 60 mil scale on walls above and below bed, respectively. (SO_3-77.5% wt, SO_2-1.3% wt, CaO-0% wt, ash-21.3% wt).		Negligible
Nozzles Slurry (1) Cooling (2)	3/8 inch scale-slurry deposit on bottom slurry spray nozzles.	North and south cooling spray nozzles were plugged.	The throat and whirl chambers of 13 of 16 bottom Spraco 8M slurry spray nozzles were severely eroded after 493 operating hours. (The remaining 3 bottom nozzles were plugged). The top 6 nozzles were in good condition. 8 of 16 bottom slurry nozzles were replaced with new Spraco 8M nozzles.
Chevron SS Demister	20 mil scale on bottom vanes; 50 mil scale on top vanes of composition (SO_3-81.5% wt, CaO-0% wt, SO_2-1.1% wt, ash-16.8% wt).	At middle vane, 1/3 of demister was completely plugged while 1/3 was partially plugged.	Negligible
Reheater	*	1/8 inch solids deposit in duct above reheater.	Reheater refractory cracks continued to enlarge on north side. SS sleeve was not cracked but was deformed. Sleeve was replaced.
ID Fan	*	2-3 inch deposit on bottom of inlet damper. Light solids coating on blades.	Expansion joint above ID fan still leaking. (See run 505-3A report of June 4th). Discharge is of low pH (about 2.4).
Miscellaneous	20-45 mil scale in suction lines of G-303A and B pumps. (CO_2-10% wt, SO_2-1% wt, SO_3-72.5% wt, ash-5.6% wt, CaO-1.5% wt).	About 8% of bed was plugged; 14% in stratified pattern.	Flake lining in tank D-301 scraped (0.105 inch groove) by the 8 inch overflow weir downcomer. The downcomer was installed during the March 31, 1973 outage.

* Denotes not applicable or not inspected.

(1) Bottom Header - Spraco 8M nozzles.
Top Header - Spraco 8M nozzles.
(2) Three Bete Fog, ST 32FCN nozzles.

Table C-36

Run No. 507-3A and 508-3A On Stream Hours 37 Hours Operating Dates 7/10/73 - 7/11/73

Component	Scale	Solids Deposits	Deterioration During Test Run Or At Time First Noticed
Gas Inlet Duct	Negligible	2 ft^2 of 1 inch deep solids.	Negligible
Marble Bed Scrubber	20 and 10 mil scale deposited on walls and slurry piping beneath and above marble bed during the above period.	3/4 - 1 inch solids on west two bottom slurry pipes.	*
Nozzles Slurry (1) Cooling (2)	*	*	5 of 16 bottom slurry nozzles were plugged. North cooling spray nozzle was partially plugged.
Chevron SS Demister	15 mil scale on extreme north and south sections of top vanes.	1/8 and 1/4 inch solids on north and south quadrants of bottom vanes. Remainder of bottom vanes covered only with dust coating.	*
Reheater	*	*	*
ID Fan	*	*	*
Miscellaneous	*	30% of the Marble bed was plugged. ΔP across bed $\leq$ 7.4 in H_2O.	*

* Denotes not applicable or not inspected.
(1) Bottom Header - Spraco 8M nozzles.
Top Header - Spraco 8M nozzles.
(2) Two, Bete fog ST-32FCN nozzles.

Appendix D

TVA INTERIM REPORT OF CORROSION STUDIES: EPA ALKALI SCRUBBING TEST FACILITY

by

G. L. Crow
H. R. Horsman

October 1, 1973

EPA ALKALI-SCRUBBING TEST FACILITY--SHAWNEE POWER PLANT

Interim Report of Corrosion Studies

Identification and solution of corrosion and erosion problems associated with construction materials are important goals in a program for the design and evaluation of limestone - wet-process systems for removing sulfur dioxide from stack gas at coal-fired power plants. The program at the Shawnee Power Plant is a cooperative effort among the Environmental Protection Agency (EPA), Bechtel Corporation, and TVA.

Earlier corrosion tests made in pilot-plant studies by the Process Engineering Branch* of limestone - wet-scrubbing systems at Colbert Power Plant showed that some materials of construction were durable while others were severely attacked under plant operating conditions (Process Engineering Branch reports--Sept. 1971, Dec. 1971, July 1972, and Aug. 1972).

At the request of the EPA in 1972, the Process Engineering Branch of TVA started corrosion tests of 17 alloys and 7 nonmetals at 21 strategic locations in three parallel scrubber systems at the Shawnee Power Plant. The systems were the venturi, the Turbulent Contact Absorber (TCA), and the Hydro-Filter; each of these had the capacity to handle 30,000 acfm of gas.

After the systems had been operated from 1700 to 2200 hours, the results of corrosion tests and of plant inspections showed that greatest corrosion had occurred in areas such as inlet ducts and venturi where wetted gas or gas and slurry flowed at high velocity. Typically, the stack gas contained 0.3% SO_2 and 3 to 5 grains of fly ash per cubic foot. Deposits of solids, such as limestone and fly ash, prevented erosion but caused corrosion of the concentration cell type in some areas. The most resistant alloys tested were Hastelloy C-276, Inconel 625, Incoloy 825, Carpenter 20 Cb-3, and Type 316L stainless steel. Hastelloy C-276 was the most durable and also the most expensive; Type 316L stainless steel ranks fifth in durability but eleventh in cost of the alloys tested. Rubbers, such as butyl, natural, and neoprene, showed good resistance. With some exceptions, units of plant equipment made of Type 316L stainless steel or lined with neoprene or with polyester inert flake material were durable. Testing work is being continued.

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*Process Engineering Branch of the Tennessee Valley Authority.

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Program and Plans

Program: The limestone - wet-scrubbing program for sulfur dioxide removal at Shawnee is funded and directed by EPA. The Bechtel Corporation designed the plant facility and TVA built it. TVA is operating the plant under a test program developed and directed by Bechtel. Evaluation of construction materials by exposure of test specimens at strategic locations and by inspection of the plant equipment is an important goal in the program.

Plans: Responsibility for conducting the evaluation program at Shawnee was assigned TVA in March 1972. /Report to Air Pollution Control Office, EPA (Contract No. PH 22-68-67, June 28, 1968), by Bechtel Corporation (March 2, 1972)./ The Process Engineering Branch of the Division of Chemical Development was given this task. /Informal memorandums--H. W. Elder to R. D. Young (April 5, 1972) and Ronald D. Young to H. W. Elder (April 7, 1972)./ This work includes procuring test materials, making test specimens, fabricating suspension equipment for spools and racks of specimens in the plants, and reporting test results. Also included are periodic inspection and evaluations of plant equipment for corrosion and wear.

Bechtel Corporation specified 20 materials of construction that consisted of 17 alloys and 3 nonmetals to be tested at 24 designated locations in the three plants. /Material List of Corrosion Coupon Test Rack (2/15/72) and Drawings SK-M-102 through 109 and SK-M-111 (Job 6955), Bechtel Corporation./

Plant Facility: Figure 1 is a view of the plant showing the three parallel scrubbing systems--the venturi, the TCA, and the Hydro-Filter.

Power plant stack gas at an average temperature of 320°F (300°-350°F) flows through a 40-inch duct to a system where it is sprayed for humidification and for cooling. It then passes through limestone slurry in a particular type of test scrubber for sulfur dioxide removal. Afterward, it is freed of mist in a separator, reheated to between 235° and 265°F to vaporize mist and eliminate a plume, and discharged through a fan and duct to the atmosphere. Scrubber effluent is clarified to remove solids which are discarded and the liquor is then recirculated.

Some features common to all the systems are described below. A 40-inch duct is used to carry the stack gas at 320°F from the No. 10 boiler of the power plant to a test system; each duct is made of 10-gage carbon steel, ASTM A-283, and is insulated except at flanged joints. The 40-inch duct connects to another gas duct made of Type 316L stainless steel. This duct is equipped with two sets of spray nozzles (the first for humidifying and the second for cooling the gas) and an air-operated soot blower.

Downstream from each sulfur dioxide absorber and mist eliminator unit there are a stainless steel duct, a refractory-lined reheater fired with fuel oil, an induced-draft fan of stainless steel, and a stack of stainless steel. For liquor handling there are a slurry recirculation tank, a scrubber effluent tank, and a liquor clarification system. The effluent hold tank and a clarifier tank are made of carbon steel A-283 and coated inside with Flakeline 103 which is a Bisphenol polyester resin-fiber glass coating manufactured by the Ceilcote Company. The recirculation tank, clarified water storage tank, and reslurry tank are made of carbon steel and lined with neoprene.

Distinguishing features of the systems are as follows. In the venturi scrubber system shown in Figure 2, the gas is scrubbed in a venturi unit made of Type 316 stainless steel and then passed through a neoprene-lined spray tower (afterscrubber) with a chevron-type separator in the top for mist recovery. In the TCA system, shown in Figure 3, gas is scrubbed in a mobile bed of wetted balls, and the mist is removed in a Koch FlexiTray and chevron-type separator in a tower lined with neoprene. In the Hydro-Filter system shown in Figure 4, gas is scrubbed in a flooded bed of marbles, and the mist is removed in a chevron-type mist separator in a neoprene-lined scrubber tower.

Preparations for Corrosion Tests

With Bechtel's approval, several improvements were made in plans for the design, preparation, and installation of test specimens. Nonmetallic materials added to the test materials list included Qua-Corr, a fiber glass-reinforced furan resin, and the rubbers--butyl, natural, and neoprene. Stressed specimens of five alloys were also added to detect stress-corrosion cracking under plant operating conditions.

Disks: Disk-type specimens, 2 inches in diameter, were prepared from the 17 metals. A weld was made (according to manufacturer's recommendations) across the diameter, and after being welded, the metal was cooled slowly in still air to simulate conditions of constructing or repairing large equipment. Whenever it was available, metal stock of 1/8-inch minimum thickness was used, and the surfaces were machined smooth after the welding. Some alloys available only in thinner gages could not be machined, so the weld beads were smoothed by grinding. A hole, 23/64 inch in diameter, was drilled in the center of each disk for mounting.

Three nonmetallic materials, Bondstrand 4000, Flakeline 200, and Transite, were also prepared as 2-inch disks and mounted on spools along with the metal disks. Flakeline 200, a coating material, was applied on mild steel disks by the manufacturer. Bondstrand 4000 and Transite are self-supporting materials and are obtained in sheet form for disk preparation.

Stressed: A strip approximately 1/8 by 1 by 5-1/2 inches was welded at midlength, machined to smooth all the surfaces, and formed into a U shape. One-half-inch holes were drilled in each end of the strip to accommodate a bolt (Type 316 stainless steel, 1/4 inch) fitted with Teflon insulators for applying static stress in the specimen.

Coated: Because of their large sizes of approximately 4-1/2 by 4-1/2 inches, the plate specimens of Qua-Corr plastic and the butyl, natural, and neoprene rubbers were mounted on a separate rack. Qua-Corr is a self-supporting material; the rubbers were applied on mild steel specimens by the manufacturer. The durometer "A" hardness values of the rubber-coated specimens as received were as follows: natural, 34-37; butyl, 54-56; and neoprene, 64-65.

Mounts and Suspensions: Spools and racks for mounting the test specimens and also the suspension equipment for installing them in the plants were constructed mainly of Type 316 stainless steel. Bolts and nuts were annealed to remove stresses caused by cold-working in threading operations. To prevent loss of fasteners through vibration of equipment, two nuts were locked by forcing them together.

At some test locations inside plant equipment, brackets were attached as permanent fixtures by welding, and then the spools of specimens were bolted to them. In other locations, spools were fastened to existing pipes by the use of band-type clamps. In a tank, spools were suspended by means of a 1/8-inch strip or a 3-inch pipe that was bolted to the top. Sleeves (3/8-inch wall by 6 inches long) of soft butyl rubber were placed around the 3-inch specimen support pipe as cushions to prevent abrasion damage to the Flakeline coating or neoprene lining on a tank wall. No specimens were installed inside pipelines or fittings.

Figure 5 shows the three types of assemblies used for mounting the corrosion test specimens. These were:

(A) Stressed--with 5 U bends

(B) Rack--with three rubber-coated plates and one plastic plate

(C) Spool--with 20 disks consisting of 17 alloys and 3 nonmetals

A Teflon sleeve was used to insulate the specimens from the supporting stainless steel bolt, and Teflon spacers or washers were used to prevent contact of the dissimilar materials.

Figure 6 shows prepared specimens and support equipment before shipment from the Office of Agricultural and Chemical Development (OACD) to Shawnee in August 1972. A few racks of specimens are shown attached to 3-inch pipe and to 1/8-inch-thick strap.

Test Exposures, Conditions, and Procedures

Test specimens of materials listed in Tables I, II, and III were installed in the three plant systems in August 1972. Table IV gives the analysis of each of the 17 metals tested. Specimens were exposed at test locations identified by series 1000, 2000, and 3000 as shown in Figures 2, 3, and 4; however, specimens (1004-6) were omitted in the venturi after-scrubber tower that was to be modified. All specimens remained in the scrubber systems from August 12, 1972, to February 3, 1973, except those in the TCA system which were temporarily removed for preliminary evaluation in November 1972.

Plant Operation: Usually, one system was operated at a time, although all three could be operated simultaneously. Operating hours in the exposure period are shown below.

System	Hours	
	Idle	Operated
Venturi	2340	1840
Turbulent Contact Absorber	2535	1667
Hydro-Filter[a]	1950	2203

[a] Also called marble bed.

Plant Process Materials and Deposits: Typical compositions of inlet and outlet gas at the scrubber systems are tabulated below.

Component	Stack gas	Scrubbed gas
SO_2, %	0.3	0.05-0.2
CO_2, %	13	12
N_2, %	74	69
O_2, %	4.5	4
H_2O, %	8	15
Fly ash, gr/std ft^3	3-5	0.02

Temperature of the inlet stack gas from unit 10 boiler averaged 320°F (300°-350°F) and that of the exhaust gas after being reheated was 235° to 265°F.

Ranges in properties of liquor in the different tanks of the three scrubber systems are summarized below.

	Liquor in tanks		
	Recycle	Effluent	Clarifier
Temperature, °F	70-125	75-130	70-100
Solids, % by weight	4-15	4-10	0-30
pH	5.3-6.4	5.6-6.8	6.0-7.6
Composition, % by weight			
$CaSO_4 \cdot 2H_2O$	1.0-3.0	1.0-2.0	0-6
$CaSO_3 \cdot 1/2H_2O$	1.5-5.0	1.5-3.5	0-10
Unreacted limestone plus fly ash	1.5-7.0	1.5-4.5	0-15
Water	85-96	90-96	70-100

Table V shows analyses of deposits from the three systems in the plant. These scale and solid deposits from tanks and scrubber equipment exposed to the limestone scrubbing liquor in the three systems were composed mainly of calcium, sulfite, sulfate, and carbonate in the ranges of percentages shown below.

Component	Percent by weight
CaO	26-41
SO_2	9-18
SO_3	24-47
CO_2	0.5-6

Soot that deposited in stacks above the gas reheater contained the following on a dry basis: 27 to 64% ash and 36 to 73% hydrocarbon. Moist soot contained 2 to 13% H_2O.

Exposed Specimens: Pictures were made of specimens when removed from the plant as shown in Figures 7-12. Then the specimens were cleaned and their corrosion rates and physical condition were determined as shown in Tables I through III along with properties of gas and liquor at various test points.

Inspections of Plant: Equipment in the plant systems was inspected for corrosion and erosion damage during the first week of February 1973.

Durometer "A" hardness values of rubber lining on equipment and on test specimens were measured with a Shore instrument--Type "A-2," ASTM 2240. Unfortunately, hardness of most lined plant equipment was not determined before plant operation; so data from the rubber vendors were ordinarily used as reference values. Temperature of the atmosphere varied from 35° to 60°F as did the temperature of equipment during the plant inspection. A decrease in temperature would be expected to increase rubber hardness. Values for neoprene linings are summarized in Table VI for the plant equipment and in Table VII for test specimens after exposure to plant operating conditions.

Results of Plant Inspections and Corrosion Tests

In this section, plant inspections are described first, and then the results of corrosion tests under different exposures in equipment are given. Some of the observations on plant equipment were made by or in collaboration with R. E. Wagner and R. C. [illegible], engineers with TVA at Shawnee Power Plant.

Carbon Steel Ducts for Inlet Stack Gas--Plant Equipment: A product of general corrosion thinly coated the inside walls of these ducts where they had been insulated. A thicker corrosion product covered inner walls of uninsulated duct sections (at flanges) because heat loss through bare metal to air cooled the stack gas and condensed corrosive liquid containing carbon dioxide, oxygen, and sulfur oxides. Such localized corrosion was pronounced in the Hydro-Filter duct; and subsequently in February 1973, the plant personnel fully insulated this duct as well as those to the other systems.

Small quantities of fly ash had deposited in ductwork areas where the gas flow changed directions, but this caused no apparent problem.

Stainless Steel Ducts for Inlet Stack Gas--Plant Equipment: In each duct between the carbon steel section and the scrubber unit there are: three nozzles of Type 316 stainless steel for spraying liquid to humidify gas, and one nozzle of Type 309 stainless steel for blowing air to dislodge soot. At the TCA and the Hydro-Filter (but not the venturi) scrubbers, there are four nozzles of Carpenter 20 alloy for spraying recycle slurry to cool the inlet gas.

The ducts, in general, were not appreciably corroded. Slight abrasion occurred in areas which were not coated by solids, but corrosion of the concentration cell type was present under the accumulations of solids.

Spray nozzles for gas humidification in these ducts were operated for the number of hours shown below.

Duct to	Spray hours	Percent of operating hours
Venturi	567	31
TCA	0	0
Hydro-Filter	2203	100

The conditions of the soot blower nozzles were as follows: at TCA--good, and at Hydro-Filter--severely corroded. (The nozzle in the venturi system was not inspected.) Nozzle corrosion at the Hydro-Filter was attributed to the use of the water sprays for gas humidification upstream which would yield hot corrosive mist containing carbon dioxide, oxygen, and sulfur oxides.

Two of the four nozzles of Carpenter 20 stainless steel used for cooling gas to the TCA scrubber were plugged and two were severely eroded internally. Erosion was caused by high-velocity flow of cooling slurry consisting of water, limestone, and fly ash.

Stainless Steel Ducts for Inlet Stack Gas--Corrosion of Test Specimens: Specimens located in ducts below gas humidifier sprays corroded as follows in mils per year: 1 to more than 330 in venturi system, 1 to 17 in TCA, and 1 to more than 300 in Hydro-Filter. (See points 1002, 2002, and 3002 on Figures 2-4.) The high rates in ducts to the venturi and Hydro-Filter systems are attributed to previously mentioned hot corrosive spray from humidifier spray operation. (Compare 1002, 2002, and 3002 on Figures 7, 9, and 11, respectively.) Type 316L showed good resistance in the venturi and TCA ducts but had localized attack (18-mil groove and minute pits) in the Hydro-Filter duct. Other, more expensive alloys, such as Hastelloy C-276 and Inconel 625, showed good resistance in the ducts to the three systems as well as in other parts of the systems as described later.

In the duct to the TCA system where no humidification was used, the temperature of the gas was 260° to 330°F, and the conditions of the nonmetal specimens were: Transite--good, Flakeline 200--fair, and Bonstrand--poor. All three of the materials were in poor condition in humidified gas to the venturi and Hydro-Filter units.

Venturi Scrubber--Plant Equipment: Bolts and nuts of Type 304 stainless steel used to assemble internal parts of the venturi scrubber had failed twice in plant operation before they were replaced with ones of fully annealed Type 316 stainless steel.

The neoprene-lined duct between the venturi unit and the after-scrubber tower was in good condition. Durometer A hardness of the lining was 67.

Venturi Scrubber--Corrosion of Test Specimens: The specimens were installed directly below the vertically mounted venturi as shown at point 1C11 of Figure 2. Gas and slurry (laden with compounds of sulfur oxides) at a high velocity caused more severe corrosion and erosion damage to specimens in this location than in any other in the three systems. Specimens of nine alloys and three nonmetals failed. Figure 7 shows that spool 1011 was clean and only 8 of the 20 test specimens remained at the end of the 1840-hour test period. The five alloys that showed the lowest corrosion in mils per year were: Hastelloy C-276--5 mils, Inconel 625--5 mils, Incoloy 825--7 mils, Carpenter 20 Cb-3--14 mils, and Type 316L stainless steel--15 mils.

The other three remaining alloys and their corrosion rates were: Cupro-nickel 70-30--49 mils, Monel 400--57 mils, and Hastelloy B--100 mils.

The three rubbers (butyl, natural, and neoprene) were in good condition, but the plastic Qua-Corr failed as shown fourth from the left on 1011 in Figure 8. Both Figures 7 and 8 show severe erosion damage to the chemically resistant Teflon spacers on the spools at location 1011.

Towers in the Venturi, TCA, and Hydro-Filter Systems--Plant Equipment: In general, the neoprene lining on the wall of each tower was in good condition (Table VI). Hardness values and comments are listed below.

Tower	Durometer hardness Original[a]	 Measured[b]	Comment
Venturi (afterscrubber)	60-65	52-60	Wear was apparent in a small area near a nozzle. The highest hardness was near the top and the lowest was near bottom of the tower.
TCA	60-65	53-63	Highest hardness was in the mid-section and the lowest was near bottom and top of the tower.
Hydro-Filter	60-65	65-72	Slight impact damage was probably caused by foreign sharp objects. Highest hardness was in the mid-section and the lowest was near the top of the tower.

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[a] From vendor's data--hardness was not measured in the plant before tower operation.

[b] Measurements in plant were not made at same temperature because of weather changes.

Solids deposition in the towers varied as described below:

Tower	Deposition
Venturi (afterscrubber)	A heavy deposit was present as follows: on the walls below trapout tray in bottom; on a 30-inch-wide band of the wall below the mist eliminator (chevron); and on bottom (1/2 the area) of the mist eliminator near top of tower.
TCA	Multilayered deposits of solids covered the walls of the tower. These decreased in thickness from 1 inch at bottom to 1/16 inch at top. The mist eliminator (chevron) was partly clogged. No loose solids were present because the unit was cleaned 2 weeks before the inspection.
Hydro-Filter	Scale, 1/16 inch thick, was on walls, piping, and spray nozzles. Slurry deposit was 1/4 to 1/2 inch thick on a narrow band of wall below and adjacent to the mist eliminator and on the bottom of the mist eliminator.

Corrosion of Type 316 stainless steel components of the towers ranged from mild to severe as described below.

Venturi (afterscrubber)	Surfaces under solid deposits had generally developed small pits. The wall of the outlet duct below the gas reheater, although clean, was pitted.
TCA	Grids that supported packing showed negligible corrosion, but their top surface showed some abrasion from the moving bed of wetted balls. The Koch FlexiTray was clean and showed no apparent corrosion after 985 hours' service. However, the top side of the mist eliminator (chevron) had undergone severe general corrosion and pitting after 1667 hours' service.
Hydro-Filter	Corrosion of the mist eliminator (chevron) and other components of Type 316L stainless steel in this tower was not detected.

Spray nozzles of Type 316 stainless steel were generally in good condition after handling slurry in the venturi afterscrubber and the TCA towers, but nonmetal nozzles in the Hydro-Filter tower were damaged. Four of 16 nozzle locations had been previously blanked when nozzles had failed and no spares were available. Some of the plastic nozzles beneath the glass sphere bed in the Hydro-Filter were damaged and had been replaced with nozzles of improved design. The remaining original nozzles were badly worn, and two of four improved design nozzles had failed. Of six soft rubber nozzles at a higher level in the Hydro-Filter, four were badly eroded; in one, the lining of the whirl chamber had torn so as to plug the outlet, and the casing was cracked.

Towers in the Venturi, TCA, and Hydro-Filter Systems--Corrosion of Test Specimens: In the afterscrubber of the venturi system, specimens were not installed because of plans to alter the arrangement of sprays.

In the TCA scrubber tower, test specimens were mounted at three elevations (see Figure 3 and Table II). Those above the third grid for holding mobile packing hollow plastic spheres at location 2006 were exposed to gas and liquor. Those below the FlexiTray at 2005 were exposed to gas and droplets, and those below the chevron mist eliminator at 2004 were exposed to gas and mist. Figure 9 shows that spools of specimens which had been exposed at 2006 and 2005 were partly covered by solids, but those at 2004 were clean. In the period August 12 through November 3, 1972, movement of the mobile bed had caused some erosion at 2006. The eroded specimens were replaced with new ones that were placed within a wire mesh container to protect them from erosion by the balls. At all three locations, the corrosion rates were 1 mil per year or less for Carpenter 20 Cb-3, Hastelloy C-276, Incoloy 825, Inconel 625, and

Type 316L stainless steel. Gas and mist at 2004 below the mist eliminator caused crevice corrosion on Incoloy 825 and minute pitting on Type 316L stainless steel. It also caused the greatest corrosion of mild steel (250 mils) and Cor-Ten B (268 mils per year). Pitting and/or crevice corrosion occurred on most of the other alloys exposed in this tower. The corrosion of stressed specimens 2004 shown in Figure 10 was about equal to that of the counterpart disk specimens in Figure 9.

The condition of the nonmetallic materials tested in the TCA tower ranged from poor to good. The three specimens of rubber and two of the three specimens of Bondstrand were in good condition.

In the tower of the Hydro-Filter system, tests of corrosion specimens were conducted at two locations (see Figure 4 and Table III). One was in the liquor and inlet gas at 3006 below the marble support grid, and the other was in the gas and liquor at 3005 above the marble bed (see Figures 11 and 12). All of the test specimens were coated with scale and deposit. The following alloys were corroded at rates of 1 mil per year or less: Carpenter 20 Cb-3, cupro-nickel 70-30, Hastelloy C-276, Incoloy 825, Inconel 625, and Type 316L stainless steel. Monel 400 and Hastelloy B had rates of less than 1 to 4 mils per year in the two locations. Mild steel and Cor-Ten B had the greatest rates--37 and 40 mils per year, respectively, above the marble bed; and 14 and 13, respectively, below the bed. Pitting and/or crevice corrosion occurred on the other alloys. In the liquor and inlet gas at 3006, Bondstrand was good, and the Flakeline and Transite were fair. In the gas and liquor at 3005, Bondstrand Qua-Corr, and the three rubbers were good, and the Flakeline was fair.

Exhaust Gas Systems--Plant Equipment: Each exhaust gas reheater for heating the scrubbed gas to between 235° and 265°F is identical in the three systems (Figures 2, 3, and 4). The refractory lining, 3 inches thick, in all the reheaters had cracked, mainly near the burner ports. The lining of the venturi reheater had the largest cracks and was coated with fuel oil.

In the venturi stack, soot saturated with oil had deposited, and on two occasions such a deposit had ignited and burned. In the TCA exhaust stack, soot saturated with oil was also found, but no fires had occurred. In the Hydro-Filter system, the soot deposit in the exhaust duct was thinner, indicating that combustion of fuel oil in the heater had been more efficient than in the other two systems.

Downstream from the reheater in each system, there was no apparent corrosion of the stack made of Type 316 stainless steel.

At the induced-draft (I. D.) fan of each system, soot and fly ash accumulated on the fan blades and housing to depths of 1/16 to 1/4 inch. In general, the thickest deposits were on stationary parts, and the trailing faces of the blades accumulated a thicker deposit than other areas of moving parts. Deposits were smallest in the fan for the Hydro-Filter where no oil was detected. Measurements of the blades and shrouds of Type 316 stainless steel showed only slight variation in thickness from the original values determined before the plants were operated. Slight bends on the periphery of two blades on the fan for the Hydro-Filter and one blade on the fan for the TCA system probably occurred because of stress relieving, but these bends caused no apparent problems.

A stainless steel sleeve (40-inch diameter by 4 feet high) has subsequently been installed in each reheater. Also, burner nozzles of different design and having much better atomizing characteristics were installed. The sleeve and nozzles should promote essentially complete combustion of oil before hot combustion gases combine with the scrubber exhaust gas and thus should minimize problems with oil and soot deposits in the stack and fan.

Exhaust Gas Systems--Corrosion of Test Specimens: Corrosion test specimens were mounted in the exhaust stacks in each system 8 to 10 feet downstream from the reheater as shown at points 1007, 2007, and 3007 (Figures 2, 3, and 4). Temperature of heated exhaust gas in contact with the specimens was usually between 235° to 265°F. Tables I, II, and III give corrosion data. Figures 7 through 12 show the soot- and ash-covered specimens after exposure.

In the stack of the venturi system, the corrosion of the test specimens was slightly more severe than in other systems. Oil-saturated soot had caught fire and destroyed the Teflon insulators and spacers. (See item 1007 on Figures 7 and 8.) Five of the highly alloyed materials and Type 316L stainless steel were durable, however, corroding at rates of less than 1 mil per year. Five other alloys had corrosion rates of 1 to 5 mils per year, and the rates for mild steel and Cor-Ten B were 16 and 18 mils. Aluminum 3003 was pitted to a depth of 70 mils during the exposure period. Transite was in good condition after the test, but Bondstrand and Flakeline failed apparently because of overheating.

In the TCA exhaust stack, the corrosion rate was either negligible or less than 1 mil per year for eight alloys including Type 316L. (See item 2007 on Figures 9 and 10.) Cor-Ten B and mild steel had rates of 2 and 3 mils per year with minute pits. Pitting of other alloys ranged from minute to depths of 12 mils. Flakeline 200 and Transite were in good condition but Bondstrand failed.

In the stack of the Hydro-Filter system, corrosion of specimens was slightly greater than in the TCA system but less than in the venturi system. (See item 3007 on Figures 11 and 12.) Five alloys, including Type 316L stainless steel which had minute pits, were corroded at rates less than 1 mil per year. Several alloys were pitted, and the deepest pit was 18 mils in E-Brite 26-1. Attack of mild steel, Cor-Ten B, and aluminum 3003 was 4 to 5 mils per year with crevice corrosion under the Teflon insulator. Flakeline and Transite were in good condition, but Bondstrand failed.

Corrosive attack of the stressed specimens by reheated stack gas was about equal to that of the counterpart disks in each test.

Effluent Hold Tanks--Plant Equipment: An effluent hold tank 20 feet in diameter and 21 feet tall is located directly under each scrubbing tower: D-101 for the venturi, D-201 for the TCA, and D-301 for the Hydro-Filter systems. The shells are made of A-283 carbon steel coated inside (80 mils minimum thickness) with Flakeline 103 manufactured by the Ceilcote Company. This coating is a Bisphenol-A type of polyester resin filled with flake glass (25-35%).

Each tank was in good condition except for minute cracks at the junction of some baffles with the tank walls. Stains of iron rust indicated that the cracks penetrated the Flakeline coating. All cracks were within 8 feet of the bottom of a tank. The neoprene-lined agitators were in good condition, and only slight wear was noted on the leading edge of the blades. The hardness of the neoprene had changed little if any (see Table VI). The Bondstrand 5000 and the Type 316L stainless steel downcomers showed no evidence of attack in either tank. In tanks D-101 and D-301 there were slightly worn areas where the butyl rubber insulator on the specimen suspension pipe (15 feet long) had rubbed the wall.

Effluent Hold Tanks--Corrosion of Test Specimens: Corrosion test specimens were mounted in the effluent hold tanks 15 feet below the top. Figures 2 through 4 identify the locations and Figures 7 through 12 show pictures of test specimens by numbers--1008 for the venturi, 2008 for the TCA, and 3008 for the Hydro-Filter systems. Tables I through III show that corrosion was less than 1 mil per year for several alloys in the three tanks.

In the venturi system tank, nine alloys, including Type 316L stainless steel, had corrosion rates of 1 mil per year or less without localized attack. The eight other alloys were attacked locally and had corrosion rates of 1 to 18 mils per year. Four specimens were pitted up to 24 mils deep. Crevice corrosion occurred on eight specimens. The rate for mild steel was 18 mils and that for Cor-Ten B was 14 mils per year, both with crevice corrosion.

The TCA effluent hold tank was in use only during the last 45 hours of the 1667-hour operating period, so corrosion rates are less representative than those at the two other tanks which were used continually during operating periods. Corrosion was less than 1 mil per year for nine alloys. Appreciable corrosion in mils per year occurred to several metals as follows: aluminum 3003, 20; Cor-Ten B, 170; and mild steel, 210. Apparently significant general corrosion of these alloys occurred during the extended period that the tank was idle, but there was only minute pitting and no crevice corrosion.

In the Hydro-Filter tank, corrosion was less than 1 mil per year for 10 alloys, including Type 316L stainless steel, without localized corrosion. Aluminum 3003, mild steel, and Cor-Ten B were corroded at the greatest rates--2 to 5 mils per year. Pitting occurred on three alloys, and the deepest pit was 5 mils on Type 304L stainless steel. Crevice corrosion occurred on 7 alloys.

In all three of the effluent hold tanks, the following showed good resistance: the butyl, neoprene, and natural rubbers; the Bondstrand and Qua-Corr plastics; and the Transite. Because of abrasion on one face, the specimens of Flakeline 200 were in only fair condition. Flakeline 200 is similar to Flakeline 103 except that it is formulated for application by "brush or spray" instead of by "trowel or spray." Apparently, the application of Flakeline 103 coating inside the effluent tanks was superior to that of Flakeline 200 on the test specimens.

Recirculation Tanks--Plant Equipment: Each of the scrubbing systems has a recirculation tank 5 feet in diameter by 21 feet tall as follows: D-104 for the venturi, D-204 for the TCA, and D-304 for the Hydro-Filter. These tanks were lined with neoprene sheet 1/4 inch thick, and the blades and shaft of their agitators were also lined with neoprene.

The linings on all of the tank walls and the agitators were in good condition. A thin scale had deposited that would protect the surface. Durometer A hardness values for the neoprene linings, however, were not consistent (see Table VI). The hardness values were higher than the original for the lining in Hydro-Filter tank D-304, and they were lower for the agitator blades in TCA tank D-204.

Recirculation Tanks--Corrosion of Test Specimens: Corrosion test specimens were suspended 8 feet below the top in recirculation tanks D-104 (venturi) and D-304 (Hydro-Filter); they were 15 feet below the top in D-204 (TCA). See Figures 2, 3, and 4. Corrosion was negligible or less than 1 mil per year for several alloys in the three tanks (Tables I through III). The greatest attack occurred on Cor-Ten B and mild steel. Items 1012, 2012, and 3012 on Figures 7, 9, and 11, respectively, show the spools of specimens after exposure.

In venturi tank D-104, the rate for Cor-Ten B was 12 and that for mild steel was 19 mils per year. The rate of attack on the other alloys was less than 1 mil per year. Pitting and crevice corrosion occurred only on Type 410 stainless steel.

In TCA tank 204, the corrosion rate was 5 mils per year for Cor-Ten B, 5 mils for mild steel, and 2 mils for aluminum. Pitting occurred on seven alloys with the maximum depth of 10 mils on Type 304L stainless steel. Crevice corrosion occurred on four alloys.

In Hydro-Filter tank D-304, the corrosion rate was 10 mils for Cor-Ten B and 11 mils per year for mild steel. Type 410 had pits 7 mils deep and three alloys underwent crevice corrosion. The other alloys were attacked less than 1 mil per year.

In general, localized attack was less prevalent in the recirculation tanks where agitation was more vigorous than in the effluent hold tanks (except in D-201 that was used only 45 hours).

Bondstrand and Transite were in good condition after the test in each tank, but Flakeline 200 was only fair because of abrasion on one face of each specimen.

Clarifier Tanks--Plant Equipment: Clarifier tanks D-102 for the venturi and D-302 for the Hydro-Filter are 20 feet in diameter and 15 feet tall; and tank D-202 for the TCA is 30 feet in diameter by 15 feet tall. Each tank has a coned bottom that is positioned 3 to 5 feet above the foundation elevation (Bechtel drawings M-8 and M-9). The tanks are of A-283 carbon steel coated inside with Flakeline 103. Mechanical equipment inside the clarifiers is made of Type 316L stainless steel. Tank D-302 was not inspected because it was in use for testing filter equipment.

The Flakeline 103 coating in tanks D-102 and D-202 was in good condition except for cracks at the junction of the overflow weir and the wall. Iron rust had bled through the cracks. The stainless steel equipment had not been attacked. However, four carbon steel bolts used to anchor the underflow cone at the bottom of the two tanks had rusted.

Clarifier Tank--Corrosion of Test Specimens: A spool of corrosion test specimens was suspended in the fluid 5 feet below the weir in clarifier tanks D-102, D-202, and D-302. These tanks are not shown in Figures 2 through 4 (see Bechtel drawings M-8 and M-9). Items 1013, 2013, and 3013 in Figures 7, 9, and 11 are pictures of specimens after exposure. Tables I through III show corrosion data.

In the venturi tank D-102, seven alloys including Types 304L and 316L stainless steel showed negligible corrosion, and two other alloys had rates of 1 mil per year or less without localized attack. Cor-Ten B and mild steel had rates of 5 mils per year. Pitting occurred on four alloys, and the greatest depth was 12 mils on aluminum 3003. Five alloys had undergone crevice corrosion.

In the TCA tank D-202, six alloys including Type 304L and Type 316L stainless steel showed negligible attack and seven other alloys had rates of 1 mil per year or less without localized attack. Cor-Ten B and mild steel were corroded at rates of 6 and 8 mils per year. Two alloys were pitted; the deepest pit was 4 mils on Type 410 stainless steel. Localized corrosion occurred on Cor-Ten B and Type 410 stainless steel.

In the Hydro-Filter tank D-302, a total of nine alloys including Type 304L and Type 316L stainless steel corroded at less than 1 mil per year without localized attack. The rates were 7 and 9 mils for Cor-Ten B and mild steel. Four alloys were pitted; Type 410 stainless steel had the deepest pit, 16 mils, and four alloys had undergone crevice corrosion.

Transite was in good condition in the three clarifier tanks; Bondstrand was good in the venturi and the TCA tanks but poor in the Hydro-Filter tank because of spalling; Flakeline 200 was fair in the three tanks.

Clarified Process Water Storage Tanks--Plant Equipment: Clarified water storage tank D-103 for the venturi and D-303 for the Hydro-Filter systems are 10 feet in diameter and 9 feet tall. Tank D-203 for the TCA system is 13 feet in diameter and 9 feet tall. Each tank has four baffles and a shell of carbon steel lined with 1/4 inch of neoprene of durometer A hardness of 55-60. Each tank has a three-blade agitator with diameter as follows: 14 inches in D-103 and D-303 and about 42 inches in D-203. The agitators and shafts are lined with neoprene.

Conditions of linings in the clarified water tanks are described below.

Tank	Tank No.	Condition of lining on
Venturi	D-103	**Tank**: Excellent **Agitator**: Noticeable wear
TCA	D-203	**Tank**: A lap joint, 8 inches long, was loose where bottom liner extends upward 1-1/2 inches to make overlap on wall liner near a baffle on west side. **Agitator**: Slight wear
Hydro-Filter	D-303	**Tank**: Good **Agitator**: Noticeable wear. Cuts at several places were possibly made by sharp foreign objects.[a]

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[a] Two pieces of thin gage metal were on floor of tank.

It appears that the durometer A hardness of the neoprene might have increased slightly up to 11 units above 60 as shown in Table VI. However, the temperature (60°F) of the linings during the inspection was lower than the standard (73°F) specified in the ASTM designation, D2240-68.

Reslurry Tank--Plant Equipment: Tank D-401 is used for reslurrying waste solids removed in the clarifier. It is identical in size and in construction to storage tank D-103 already described. All the neoprene linings were in good condition and hardness tests were not made.

Neoprene-Lined Centrifugal Pumps--Plant Equipment: During the corrosion tests in the scrubbing systems, Hydroseal pumps were in service; impeller diameters were 12, 17, or 20 inches. These centrifugal pumps were manufactured by the Allen-Sherman-Hoff Company. All wetted parts were lined with neoprene of a durometer A hardness specified to be 54 to 56.

When the pumps were dismantled, inspection showed that the linings were not damaged severely in any except pumps discussed later. However, wear of varying degrees was found. The grooving of neoprene linings on impellers and casings was least in the TCA system and greatest in the Hydro-Filter system. General wear of the linings was slight, but a little more noticeable in the Hydro-Filter system. A durometer A hardness of the liners ranged up to 16 above the specified maximum; this was fairly general for the three systems. (The temperature of the linings when tested was below the standard of 73°F; this would cause higher values.)

Packing glands caused severe wear on the stainless steel components of pumps G-102 and G-202; these are the thickener underflow pumps for slurry containing about 30% solids.

The output of slurry feed pumps, G-108 and G-208, had decreased over a period of weeks. These are rotary screw-type pumps (Moyno) used for pumping limestone slurry containing about 60% solids. Inspection revealed that increased clearance between the stator and the rotor, because of wear of the rubber lining of the stator, allowed excess leakage. This was corrected by replacement of worn parts.

Pump G-401, reslurry tank pump, was dismantled for modification. The rubber-lined impeller and casing were neither grooved nor worn appreciably. Hardness values of the linings were not determined.

Some of the Hydroseal pumps have been replaced since February with Centriseal pumps produced by the same manufacturer. Sealwater required at the Hydroseal pumps had added more water to the system than could be tolerated for closed-loop operation.

Valves--Plant Equipment: The stainless steel check valves at the discharge of several pumps for each scrubber system were inspected. These valves are ASTM A-351, Grade CF-8M body, Type 316 plate, and neoprene seal. Generally, these valves had worn slightly and their surfaces were smooth and polished.

The 4-inch neoprene pinch valve upstream (of FE 1061) from the bottom slurry header in the afterscrubber tower of the venturi system showed no signs of chemical attack and only slight evidence of wear.

Piping--Plant Equipment: Neoprene-lined piping was inspected at the inlet to all pumps that were dismantled for inspection or seal modification in the three scrubber systems. Elbows, tees, and open ends of the piping showed no evidence of wear or deterioration. The neoprene lining 3/16 inch thick with a specified durometer A hardness of 50 plus or minus 5 was applied by the Rubber Applicators, Houston, Texas. Hardness values were not determined during the inspection.

Discussion

Process Materials: In the SO_2 removal plant, the inlet stack gas, the limestone absorbent, and their reaction products are corrosive or abrasive. Components of stack gas, such as CO_2, O_2, and SO_2, dissolve sparingly to make condensate or water corrosive. Fly ash in stack gas and the limestone in absorbent slurry are abrasive, especially in high-velocity streams. Slurry containing limestone, sulfite, sulfate, and fly ash forms deposits on metal to cause localized corrosion. (In future tests, chloride in gas or in makeup water should be considered along with compounds of sulfur as a likely corrosive in areas where it might be concentrated in a residue.)

Materials of Construction: Materials in the plant consist mainly of: carbon steel in the inlet duct for stack gas from the power plant; stainless steel, Type 316L in the scrubbing system ducts, the venturi scrubber, removable internal parts of scrubber towers, the outlet gas duct, the fans, and stack; neoprene-lined carbon steel in the venturi afterspray, TCA, and Hydro-Filter towers; neoprene-lined carbon steel in the recirculation, clarified process water, and reslurry tanks; Bondstrand and Type 316L stainless steel downcomers to the effluent hold tank; Flakeline 103-lined carbon steel in the effluent hold and clarifier tanks; refractory-lined gas reheater; and neoprene-lined pumps and piping.

Corrosion--Plant Equipment: In general, materials used in construction of the three scrubbing systems showed good resistance to attack. Carbon steel ducts were slightly attacked by inlet stack gas when at temperature below the dew point.

Inlet stack gas, after being humidified by spray water, attacked stainless steel ducts and nozzles as follows: slight erosion of bare duct surfaces; concentration cell-type corrosion (pitting and crevice) of surfaces underlying deposits; and severe corrosion and erosion of surfaces (nozzles or projections) subjected to impingement.

In the venturi scrubber, the limestone slurry and gas discharging at high velocity corroded and eroded stainless steel parts, but apparently did not damage neoprene lining in the duct.

In the towers of the three systems, slurry and gas flowing at low velocity caused only slight corrosion and erosion of bare removable parts of stainless steel, such as packing supports and FlexiTrays. Movement of the mobile packing (hollow plastic spheres similar to Ping-Pong balls) caused some erosion of grid wire in the TCA absorber.

Cause for severe corrosion on the top surface of a chevron-type mist eliminator in the TCA tower is not known. However, it is likely that some mist passing through a Koch FlexiTray located below would collect on the chevron mist eliminator and evaporate to form a residue high in compounds of chlorine and sulfur which would be corrosive. Pits observed in the outlet duct from the venturi afterscrubber might also have been caused by such a residue of chlorine and sulfur compounds. Periodic washing to remove residue might decrease the corrosion.

Nozzles of stainless steel were more durable than those of rubber or plastic for spraying limestone slurry in the towers.

Rubber lining on the tower shells, though coated usually with slurry solids, was generally in good condition.

Exhaust gas stacks of Type 316L stainless steel were apparently in good condition after exposure to gas reheated to between 235° and 265°F. Sleeves and improved burner nozzles installed at the gas reheaters should improve fuel oil combustion and thereby minimize troublesome soot deposition and a potential fire hazard in exhaust gas stacks.

Flakeline 103 linings in the effluent hold tanks and clarifier tanks were generally in good condition except for cracks near attachments, such as baffles and weirs, to the walls. Bondstrand downcomers were in good condition to effluent hold tanks.

Neoprene linings were in good condition in the recirculation, clarified water, and reslurry tanks. Slight to noticeable wear was apparent on neoprene-lined agitators in these tanks. Neoprene-lined piping was inspected near pumps and it appeared to be in good condition. The neoprene linings of casings and impellers in centrifugal pumps were not severely damaged, and the least wear was on those in the TCA system and the greatest on those in the Hydro-Filter system. Decreased output of limestone slurry (60% solids) by two rotary screw-type pumps (Moyno) required that neoprene-lined stators be replaced. The rotors are of stainless steel.

Corrosion--Test Specimens: In general, the least attack occurred to test specimens in the TCA system and the greatest to those in the venturi system. With few exceptions, the greatest loss of weight from metal specimens occurred in inlet duct areas exposed to wetted flue gas and in venturi outlet area exposed to slurry and gas at comparatively high velocities. Damage to some nonmetallic materials occurred in these areas also. Slurry impingement on the specimens caused erosion and corrosion. Pitting and crevice-type corrosion were minor where erosion and general corrosion kept the specimens clean. Generally, in most areas where solids accumulated in the three scrubber systems, the surface of the underlying specimens showed localized corrosion. However, each of the 17 alloys tested showed good resistance at one or more test locations in each scrubber system. The three rubbers were tested at only six locations; they showed good resistance in all tests. The maximum service temperature was exceeded for some nonmetallic materials in the inlet gas duct and exhaust gas duct.

Table VIII is a summary of data from all the corrosion tests conducted in the three different scrubber systems. It shows the comparative resistance of the materials tested without identifying the test conditions. The metals are grouped into four categories with respect to decreasing corrosion resistance. The evaluation is based on corrosion rates determined by weight loss and/or resistance to pitting, crevice corrosion, and other types of localized attack.

Corrosion of Hastelloy C-276 was negligible to 5 mils per year; this alloy showed no evidence of localized attack in any test location. Next in resistance were the alloys Inconel 625, Incoloy 825, Carpenter 20 Cb-3 and Type 316L stainless steel with corrosion rates ranging from negligible to 5, 7, 14, and 15 mils per year, respectively. These alloys had very few pits and/or corrosion crevices. One specimen of Type 316 stainless steel was grooved and the weld of another was attacked.

Three nonferrous alloys, cupro-nickel 70-30, Monel 400, and Hastelloy B, had minimum rates of less than 1 mil and maximum rates of 49, 57, and 100 mils per year, respectively, with one or two specimens pitted. In three tests of Monel and in one test of cupro-nickel 70-30, the welds were inferior to the parent metal.

A group of five alloys that included Type 446 stainless steel, E-Brite 26-1, Incoloy 800, USS 18-18-2, and Type 304 stainless steel, had rates that ranged from negligible to a "greater than" value which indicates that the specimen was completely destroyed at one or more test locations. The values for failures ranged from greater than 140 mils per year for Type 446 to greater than 200 for both USS 18-18-2 and Type 304L stainless steels. These five alloys were highly susceptible to localized corrosion.

Another group of alloys which consisted of Type 410 stainless steel, aluminum 3003, mild steel A-283, and Cor-Ten B had minimum rates of less than 1 mil per year and maximum rates of greater than 250 for Type 410 to greater than 1400 for mild steel and Cor-Ten B. Pitting and crevice corrosion occurred on these four alloys.

In general, the stressed specimens (5 alloys only) were not corroded at rates higher than their counterpart disk-type specimens, and no cracks were observed.

Of all the alloys tested, Hastelloy C-276 was the most durable and also the most expensive. Type 316L ranked fifth in durability and about eleventh in cost. The values for cost comparison are based on costs of tubing and sheet with Type 304 stainless steel as unity (1.00). (See Table VIII.)

Specimens of Bondstrand 4000, Flakeline 200, and Transite were tested at 21 locations. Bondstrand showed good resistance in 12 tests and poor in 9 tests. The evaluations for Flakeline were: 2 good, 14 fair, and 5 poor; and those for Transite were: 14 good, 2 fair, and 5 poor. Only six specimens of each of the plastic Qua-Corr and of the rubbers, butyl, natural, and neoprene, were tested. The results were five good and one poor for Qua-Corr and six good for each of the rubbers.

Summary

Test specimens and equipment exposed for about 6 months in three test SO_2 removal systems at Shawnee Power Plant were evaluated for corrosion and wear.

The most severe damage occurred in plant areas exposed to humidified stack gas containing fly ash, CO_2, O_2, and SO_2 at elevated temperature and high velocity; to gas and slurry discharging at high velocity from the venturi; and to gas and mist leaving an absorber.

Metals covered by limestone-fly ash deposits were not eroded but were subject to corrosion of the concentration cell type.

Neoprene-lined towers, ducts, and tanks, as well as rubber-lined test specimens, were durable. Some wear was apparent on neoprene linings of pumps and agitators.

In limited tests, reinforced plastics, such as polyester, epoxy, and furan, were less durable than rubber as lining materials.

Seventeen alloys were tested in twenty-one exposure areas in three systems of the plant. The maximum corrosion rates in mils per year for the five most durable specimens were as follows: Hastelloy C-276, 5 mils; Inconel 625, 5 mils; Incoloy 825, 7 mils; Carpenter 20 Cb-3, 14 mils; and Type 316L stainless steel, 15 mils. Hastelloy C-276 is the most durable and expensive of all the alloys tested; Type 316L stainless steel ranks fifth in durability and about eleventh in cost.

This corrosion study is being continued on materials of construction for the SO_2 removal test facility at Shawnee Power Plant.

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TABLE I

Corrosion Tests Conducted in the Venturi System of the Limestone - Wet-Scrubbing Process for Sulfur Dioxide Removal from Stack Gas at Shawnee Power Plant

(Test period--Aug. 12, 1972, to Feb. 2, 1973; operating time--1840 hours or 76.7 days; and idle time--2340 hours or 97.5 days)

Corrosion specimens						
Exposed in	Inlet gas	Gas and spray	Exhaust gas (heated)	Effluent liquor	Recycle liquor	Liquor in clarifier
Locations (See Fig. 2), Reference No.	1002	1011	1007	1008	1012	1013
Gas						
Temperature, °F	275-330[a]	80-170	235-265	-	-	-
Velocity, ft/sec	20-60	15-45	20-60	-	-	-
Flow rate, 1000's of actual ft^3/min	10-30	8-25	10-30	-	-	-
Composition, % by volume						
SO_2	0.3	0.2	0.2	-	-	-
CO_2	13	12	12	-	-	-
N_2	74	69	69	-	-	-
O_2	4.5	4	4	-	-	-
H_2O	8	15	15	-	-	-
Fly ash, gr/standard ft^3	3-5	0.02	0.02	-	-	-
Liquor						
Temperature, °F	-	-	-	90-130	70-125	70-100
Solids, % by weight	-	-	-	4-10	4-10	0-20
pH	-	-	-	5.8-6.8	5.6-6.3	6.0-7.0
Composition, % by weight						
$CaSO_4 \cdot 2H_2O$	-	-	-	1.0-2.0	1.0-2.0	0-4
$CaSO_3 \cdot 1/2H_2O$	-	-	-	1.5-3.5	1.5-3.5	0-7
Unreacted limestone plus fly ash	-	-	-	1.5-4.5	1.5-4.5	0-10
Water	-	-	-	90-96	90-96	80-100
Corrosion rate of metals[b], mils/yr						
Aluminum 3003, weld ER1100	> 160	> 550	P70	P24, -[c]	< 1	P12, -[c]
Carpenter 20Cb-3, weld Carpenter 20Cb-3	< 1	14	< 1	Neg.	Neg.	Neg.
Carpenter 20Cb-3, weld Carpenter 20Cb-3, stressed	-	-	< 1	Neg.	-	-
Cor-Ten B, weld E8018-C3	> 290	> 1400	18, -[d]	14, -[c]	12	5, -[c]
Cupro-nickel 70-30, weld B259 RCuNi	13	49	P18, -[d]	1	< 1	1
E-Brite 26-1, weld E-Brite 26-1	> 140	> 190	Pm, -[d]	< 1	Neg.	Neg.
E-Brite, 26-1, weld E-Brite 26-1, stressed	-	-	< 1	Neg.	-	-
Hastelloy B, weld Hastelloy B	28	100	-[d]	2, Pm	< 1	< 1, Pm
Hastelloy C-276, weld Hastelloy C-276	< 1	5	-[d]	Neg.	< 1	Neg.
Incoloy 800, weld Inconel 82	48, -[e]	> 190	< 1	< 1	< 1	Neg.
Incoloy 825, weld Incoloy 65	< 1	7	< 1	< 1	< 1	< 1
Incoloy 825, weld Incoloy 65, stressed	-	-	1	Neg.	-	-
Inconel 625, weld Inconel 625	< 1	5	< 1	< 1	Neg.	Neg.
Mild steel A-283, weld E6012	> 330	> 1400	16, -[c]	18, -[c]	19	5
Monel 400, weld Monel 400	10	57[f]	4	1	< 1	1, P2
Type 304L, weld Type 308L	65, -[e]	> 200	1	< 1, -[c]	Neg.	Neg.
Type 304L, weld Type 308L, stressed	-	-	2	< 1, -[c]	-	-
Type 316L, weld Type 316L	1	15, -[f]	< 1	Neg.	< 1	Neg.
Type 316L, weld Type 316L, stressed	-	-	< 1	Neg.	-	-
Type 410, weld Type 309	> 130	> 250	5, -[d]	P12, -[c]	P3, -[c]	< 1, -[c]
Type 446, weld Type 309	> 103	> 140	1	< 1, -[c]	Neg.	< 1, -[c]
USS 18-18-2, weld Inconel 82	> 140	> 200	2	P5, -[c]	Neg.	P10, -[c]
Evaluation of nonmetallic materials[g]						
Plastics						
Bondstrand 4000 (Fiber glass-reinforced epoxy).	Poor	Poor	Poor	Good	Good	Good
Flakeline 200 (Inert flakes and polyester resin).	Poor	Poor	Poor	Fair[h]	Fair[h]	Fair[h]
Qua-Corr(Fiber glass-reinforced furan resin)...	-	Poor	-	Good	-	-
Rubbers						
Butyl 26666 (Copolymer of isobutylene isoprene).	-	Good	-	Good	-	-
Natural 1575 (Polyisoprene)	-	Good	-	Good	-	-
Neoprene 9150 (Chloroprene polymer)	-	Good	-	Good	-	-
Ceramic						
Transite (Portland cement and asbestos)	Poor	Poor	Good	Good	Good	Good

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[a] No spray water was used to humidify the gas when the temperature was 275°-330°F; temperature was 125°F for 567 hours when spray water was used.

[b] The "greater than" (>) sign is used when a specimen was completely destroyed. "P" preceding a number indicates pitting during the exposure period to the depth in mils shown by the number, and "Pm" indicates minute pits. "Neg.," negligible, no weight loss or localized attack.

[c] Crevice corrosion at Teflon insulator.

[d] There was some weight loss of specimen due to wear at center hole after Teflon insulators failed when overheated.

[e] Severe localized attack of parent metal.

[f] Attack of weld.

[g] Evaluation: Good, little or no change in condition of specimen; fair, definite change, probably could be used; poor, failed or severely damaged.

[h] Evidence of abrasion on edge of specimen.

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TABLE II

Corrosion Tests Conducted in the TCA System of the Limestone - Wet-Scrubbing Process for Sulfur Dioxide Removal from Stack Gas at Shawnee Power Plant

(Test period--Aug. 12, 1972, to Feb. 3, 1973; operating time--1667 hours or 69.5 days; and idle time--2535 hours or 105.6 days)

Corrosion specimens	Inlet gas	Gas and liquor	Gas and droplets	Gas and mist	Exhaust gas (heated)	Effluent liquor	Recycle liquor	Liquor in clarifier
Exposed in	Inlet gas	Gas and liquor	Gas and droplets	Gas and mist	Exhaust gas (heated)	Effluent liquor	Recycle liquor	Liquor in clarifier
Locations (See Fig. 3), Reference No.	2002[a]	2006[b]	2005	2004	2007	2008[c]	2012	2013
Gas								
Temperature, °F	260-310	70-125	70-120	70-120	235-265	-	-	-
Velocity, ft/sec	25-60	6-12	5-10	4-8	25-60	-	-	-
Flow rate, 1000's of actual ft^3/min	15-30	11-22	11-22	11-22	15-30	-	-	-
Composition, % by volume								
SO_2	0.3	0.05	0.05	0.05	0.05	-	-	-
CO_2	13	12	12	12	12	-	-	-
N_2	74	69	69	69	69	-	-	-
O_2	4.5	4	4	4	4	-	-	-
H_2O	8	15	15	15	15	-	-	-
Fly ash, gr/standard ft^3	3-5	0.02	0.02	0.02	0.02	-	-	-
Liquor								
Temperature, °F	-	-	-	-	-	110-125	85-125	85-100
Solids, % by weight	-	-	-	-	-	6-10	7-15	0-30
pH	-	-	-	-	-	5.9-6.3	5.6-6.4	6.3-7.6
Composition, % by weight								
$CaSO_4 \cdot 2H_2O$	-	-	-	-	-	1.0-2.0	1.5-3.0	0-6
$CaSO_3 \cdot 1/2H_2O$	-	-	-	-	-	2.0-3.5	2.5-5.0	0-10
Unreacted limestone plus fly ash	-	-	-	-	-	3.0-4.5	3.0-7.0	0-15
Water	-	-	-	-	-	90-94	85-93	70-100
Corrosion rate of metals[d], mils/yr								
Aluminum 3003, weld ER1100	2	4, -[e]	4	26, P20	1, P2	20	2, P2	1
Carpenter 20Cb-3, weld Carpenter 20Cb-3	< 1	Neg.	< 1	< 1	< 1	Neg.	< 1	Neg.
Carpenter 20Cb-3, weld Carpenter 20Cb-3, stressed	-	-	-	1	< 1	2	-	-
Cor-Ten B, weld E8018-C3	15, Pm	13	21, P3	268	2, Pm	170, Pm	5, Pm	6, -[f]
Cupro-nickel 70-30, weld B259 ECuNi	2	< 1, -[g]	8, -[h]	17	< 1	3	< 1	< 1
E-Brite 26-1, weld E-Brite 26-1	< 1	P2, -[e]	P6	1, Pm	P2	Neg.	Neg.	Neg.
E-Brite 26-1, weld E-Brite 26-1, stressed	-	-	-	Pm	Pm	< 1	-	-
Hastelloy B, weld Hastelloy B	< 1	6	6	13	< 1	2	< 1	< 1
Hastelloy C-276, weld Hastelloy C-276	< 1	Neg.	< 1	Neg.	Neg.	Neg.	< 1	Neg.
Incoloy 800, weld Inconel 82	< 1	-[e], -[g]	P8, -[e]	P19, -[e]	Pm	Neg.	P2	Pm
Incoloy 825, weld Incoloy 65	< 1	< 1, -[g]	Neg.	-[e]	Neg.	Neg.	Neg.	Neg.
Incoloy 825, weld Incoloy 65, stressed	-	-	-	1, -[e]	< 1	< 1	-	-
Inconel 625, weld Inconel 625	< 1	Neg.	Neg.	Neg.	< 1	Neg.	Neg.	< 1
Mild steel A-283, weld E6012	17	26	23	250	3, Pm	210, Pm	3	8
Monel 400, weld Monel 400	1	1	1	15, -[i]	< 1	2	< 1	< 1
Type 304L, weld Type 308L	< 1, Pm	P6, -[e]	P13, -[e]	P23, -[e]	P16	Pm	P10, -[e]	Neg.
Type 304L, weld Type 308L, stressed	-	-	-	4, -[e]	< 1	Neg.	-	-
Type 316L, weld Type 316L	< 1	Neg.	< 1	Pm	< 1	< 1	< 1	Neg.
Type 316L, weld Type 316L, stressed	-	-	-	< 1, -[e]	< 1	< 1	-	-
Type 410, weld Type 309	1, Pm	Pm, -[e]	P6, -[e]	P12, -[e]	P12, -[e]	Pm	Pm, -[e]	P4, -[e]
Type 446, weld Type 309	< 1	P5, -[e]	P19, -[e]	P18, -[e]	P6	< 1	P7, -[e]	< 1
USS 18-18-2, weld Inconel 82	< 1	P4, -[e]	P8, -[e]	P16, -[e]	P5	< 1	Pm, -[e]	< 1
Condition of nonmetallic materials[j]								
Plastics								
Bondstrand 4000 (Fiber glass-reinforced epoxy).	Poor	Poor	Good	Good	Poor	Good	Good	Good
Flakeline 200 (Inert flakes and polyester resin).	Fair	Poor	Fair	Fair	Good	Fair	Fair	Fair
Qua-Corr (Fiber glass-reinforced furan resin)..	-	-	-	Good	-	Good	-	-
Rubbers								
Butyl 26,666 (Copolymer of isobutylene-isoprene).	-	-	-	Good	-	Good	-	-
Natural 1375 (Polyisoprene)	-	-	-	Good	-	Good	-	-
Neoprene 9150 (Chloroprene polymer)	-	-	-	Good	-	Good	-	-
Ceramic								
Transite (Portland cement and asbestos)	Good	Poor	Fair	Poor	Good	Good	Good	Good

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[a] No spray water was used at test location 2002 during the corrosion test period to humidify the gas.

[b] Because test specimens were worn by movement of plastic balls during the period 8/12 to 11/3/72, new specimens were installed 11/17/72. The data given were determined from the last 995 hours of operation.

[c] The specimens were immersed in the slurry only during the last 44.5 hours of operating time, and the corrosion rate was determined on this basis. However, the high rates for aluminum, Cor-Ten B, and mild steel indicate that these alloys were corroded during idle time also.

[d] The "greater than" (>) sign is used when a specimen was completely destroyed "P" preceding a number indicates pitting during exposure period to depth in mils shown by number, and "Pm," minute pits. "Neg.," negligible, no weight loss or localized attack.

[e] Crevice corrosion at contact with Teflon insulator.

[f] Localized attack of heat-affected zone of weld.

[g] Wear on edge of specimen due to movement of plastic balls.

[h] Edge of specimen damaged by impact of sharp object.

[i] Attack of weld.

[j] Evaluation: good, little or no change in condition of specimen; fair, definite change, probably could be used; poor, failed or severely damaged.

TABLE III

Corrosion Tests Conducted in the Hydro-Filter System of the Limestone - Wet-Scrubbing Process for Sulfur Dioxide Removal from Stack Gas at Shawnee Power Plant

(Test period--Aug. 12, 1972, to Feb. 1, 1973; operating time--2205 hours or 91.8 days; and idle time--1950 hours or 81.3 days)

Corrosion specimens Exposed in Locations (See Fig. 4), Reference No.	Inlet gas 3002[a]	Liquor and inlet gas 3006	Gas and liquor 3005	Exhaust gas (heated) 3007	Effluent liquor 3008	Recycle liquor 3012	Liquor in clarifier 3013
Gas							
Temperature, °F	120-150	95-135	95-130	235-265	-	-	-
Velocity, ft/sec	20-45	3-8	3-8	25-60	-	-	-
Flow rate, 1000's of actual ft³/min	10-23	10-23	10-23	12.5-30	-	-	-
Composition, % by volume							
SO_2	0.3	0.1	0.1	0.1	-	-	-
CO_2	13	12	12	12	-	-	-
N_2	74	69	69	69	-	-	-
O_2	4.5	4	4	4	-	-	-
H_2O	8	15	15	15	-	-	-
Fly ash, gr/standard ft³	3-5	0.02	0.02	0.02	-	-	-
Liquor							
Temperature, °F	-	-	-	-	75-125	75-125	75-100
Solids, % by weight	-	-	-	-	4-10	4-10	0-20
pH	-	-	-	-	5.6-6.4	5.3-6.4	6.1-7.4
Composition, % by weight	-						
$CaSO_4 \cdot 2H_2O$	-	-	-	-	1.0-2.0	1.0-2.0	0-4
$CaSO_3 \cdot 1/2H_2O$	-	-	-	-	1.5-3.5	1.5-3.5	0-7
Unreacted limestone plus fly ash	-	-	-	-	1.5-4.5	1.5-4.5	0-10
Water	-	-	-	-	90-96	90-96	80-100
Corrosion rate of metals[b], mils/yr							
Aluminum 3003, weld ER1100	> 160	P9	P18	5, -[c]	2, -[c]	< 1	P6
Carpenter 20Cb-3, weld Carpenter 20Cb-3	4, Pm	Neg.	Neg.	Pm	Neg.	Neg.	Neg.
Carpenter 20Cb-3, weld Carpenter 20Cb-3, stressed	-	-	< 1	< 1	< 1	-	-
Cor-Ten B, weld E8018-C3	> 300	40	13	4, -[c]	5, -[c]	10	7
Cupro-nickel 70-30, weld B259 RCuNi	35[d]	1	1	3	< 1	< 1	1
E-Brite 26-1, weld E-Brite 26-1	> 130	< 1, P1	Neg.	P7	Neg.	< 1	< 1
E-Brite 26-1, weld E-Brite 26-1, stressed	-	-	< 1, -[c]	<1, P18	< 1	-	-
Hastelloy B, weld Hastelloy B	71	2	4	2	< 1	< 1	< 1
Hastelloy C-276, weld Hastelloy C-276	< 1	Neg.	Neg.	< 1	< 1	Neg.	< 1
Incoloy 800, weld Inconel 82	93	< 1, P19	< 1	1	< 1	Neg.	Neg.
Incoloy 825, weld Incoloy 65	2	Neg.	< 1	< 1	< 1	Neg.	< 1
Incoloy 825, weld Incoloy 65, stressed	-	-	< 1	1	< 1	-	-
Inconel 625, weld Inconel 625	< 1	Neg.	< 1	< 1, Pm	Neg.	Neg.	Neg.
Mild steel A-283, weld E6012	> 300	37	14	4, -[c]	4, -[c]	11	9
Monel 400, weld Monel 400	50, -[d]	< 1	2	3	< 1	< 1	< 1, -[c]
Type 304L, weld Type 308L	> 140	P12, -[c]	P10	1, Pm	< 1, -[c]	Neg.	< 1
Type 304L, weld Type 308L, stressed	-	-	P18, -[c]	< 1, Pm	P5, -[c]	-	-
Type 316L, weld Type 316L	G18, Pm	Neg.	Neg.	< 1	< 1	Neg.	Neg.
Type 316L, weld Type 316L stressed	-	-	< 1, -[c]	< 1, Pm	< 1	-	-
Type 410, weld Type 309	> 100	P8, -[c]	P3, -[c]	3, -[c]	Pm, -[c]	P7, -[c]	P16, -[c]
Type 446, weld Type 309	> 90	P9, -[c]	P10, -[c]	1, Pm	< 1, -[c]	-[c]	P9, -[c]
USS 18-18-2, weld Inconel 82	> 120	P8, -[c]	P9, -[c]	2	Pm, -[c]	< 1, -[c]	P5, -[c]
Evaluation of nonmetallic materials[e]							
Plastics							
Bondstrand 4000 (Fiber glass reinforced epoxy).	Poor	Good	Good[f]	Poor	Good	Good	P13, Poor
Flakeline 200 (Inert flakes and polyester resin).	Poor	Fair	Fair	Good	Fair	Fair	Fair
Que-Corr (Fiber glass reinforced furan resin)..	-	-	Good[f]	-	Good	-	-
Rubbers							
Butyl 26,666 (Copolymer of isobutylene-isoprene).	-	-	Good[f]	-	Good	-	-
Natural 1375 (Polyisoprene)	-	-	Good[f]	-	Good	-	-
Neoprene 9150 (Chloroprene polymer)	-	-	Good[f]	-	Good	-	-
Ceramic							
Transite (Portland cement and asbestos)	Poor	Fair	Good[f]	Good	Good	Good	Good

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[a] Spray water was used at all times at test point 3002 to humidify the gas.

[b] The "greater than" (>) sign is used when a specimen was completely destroyed. "P" preceding a number indicates pitting during the exposure period to the depth in mils shown by the number, and "Pm" indicates minute pits. "Neg.," negligible, no weight loss or localized attack. "G," groove of depth in mils shown.

[c] Crevice corrosion at Teflon insulator.

[d] Attack at weld.

[e] Evaluation: Good, little or no change in condition of specimen; fair, definite change, probably could be used; poor, failed or severely damaged.

[f] Specimen was damaged by impact of sharp instrument during the exposure period.

TABLE IV

Compositions of Alloys Tested in the Limestone - Wet-Scrubbing Systems for Sulfur Dioxide Removal from Stack Gas at Shawnee Power Plant

Alloys	Chemical analysis, %												
	C	Cr	Ni	Fe	Cu	Mo	Mn	Si	P	S	Al	Ti	Others
1. Aluminum 3003	-	-	-	0.7[a]	0.2[a]	-	1.0-1.5	0.6[a]	-	-	Bal.	-	Zn 0.1[a], Total 0.15
2. Carpenter 20Cb-3	0.07[a]	19-21	32-38	Bal.	3-4	2-3	2.00[a]	1.00[a]	0.035[a]	0.035[a]	-	-	Cb + Ta 8 x C
3. Cor-Ten B[b]	0.066	0.52	0.018	Bal.	0.31	0.010	1.20	0.29	0.012	0.031	0.056	-	V 0.05
4. Cupro-nickel 70-30[b]	-	-	31.00	0.53	67.79	-	0.52	-	0.003	0.005	-	-	Zn 0.034, Pb 0.002
5. E-Brite 26-1[b]	< 0.001	26.17	0.08	Bal.	0.01	1.00	0.01	0.19	0.010	0.012	-	-	N 0.010
6. Hastelloy B[b]	< 0.01	0.19	Bal.	5.75	-	26.20	0.58	0.01	0.005	0.006	-	-	Co 0.85, V 0.26
7. Hastelloy C-276[b]	0.002	15.87	Bal.	5.96	-	16.32	0.49	< 0.01	0.012	0.010	-	-	Co 1.84, W 3.51, V 0.25
8. Incoloy 800[b]	0.04	21.11	31.32	45.01	0.40	-	0.84	0.31	-	0.007	0.48	0.46	
9. Incoloy 825[b]	0.04	22.28	42.22	28.30	2.12	-	0.56	0.34	-	0.007	0.06	0.66	
10. Inconel 625	0.1[a]	20-23	Bal.	5.00[a]	-	8-10	0.5[a]	0.5[a]	0.015[a]	0.015[a]	0.4[a]	0.4[a]	Co 1.0[a], Cb + Ta 3.15 - 4.15
11. Mild Steel A-283[b]	0.17	-	-	Bal.	0.037	-	0.48	0.070	0.015	0.024	0.005	-	
12. Monel 400[b]	0.09	-	64.66	1.00	33.06	-	1.08	0.08	-	0.008	0.004	-	
13. Type 304L	0.030[a]	18-20	8-12	Bal.	-	-	2.00[a]	1.00[a]	0.045[a]	0.030[a]	-	-	
14. Type 316L	0.030[a]	16-18	10-14	Bal.	-	2.0-3.0	2.00[a]	1.00[a]	0.045[a]	0.030[a]	-	-	
15. Type 410[b]	0.062	12.7	0.16	Bal.	0.03	0.054	0.43	0.40	0.014	0.018	0.069	-	N 0.034, V < 0.03
16. Type 446[b]	0.10	24.6	0.50	Bal.	0.045	0.10	0.71	0.37	0.018	0.010	0.008	< 0.02	N 0.18, V < 0.05
17. USS 18-18-2[b]	0.065	18.2	18.0	Bal.	0.03	0.018	1.50	1.94	0.007	0.009	0.001	-	N 0.04

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[a] Maximum.

[b] Analysis was supplied with the material received for use in corrosion tests.

Table V

Analyses[a] of Deposits in Limestone - Wet-Scrubbing Systems for Sulfur Dioxide Removal from Stack Gas at Shawnee Power Plant

Identification of sample			Composition, % by weight								
			Scale or sludge deposit						Soot material[b]		
Date	Number	Location	CaO	SO_2	SO_3	CO_2	MgO	Others	Ash	H_2O	Hydrocarbon
Venturi System											
2/1/73	VD 2173	Scale from recirculation tank D-104.	25.4	9.0	37.3	1.2	-	25.5	-	-	-
2/23/73	VD 2 2373	Soot from gas duct about 25 feet above reheater.	-	-	-	-	-	-	56.0 (64.2)	12.8 -	31.2 (35.8)
TCA System											
2/3/73	TCA D 12373	Scale from recirculation tank D-204 (Test 2012).	31.2	10.4	28.7	6.3	-	23.4	-	-	-
2/3/73	TCA D 22373	Scale from spool of corrosion specimens (Test 2006)	28.5	17.6	27.4	0.5	-	25.9	-	-	-
2/5/73	TCA D 12573	Scale from scrubber wall below and near Koch tray.	39.7	16.8	25.9	2.0	0.22	15.4	-	-	-
2/5/73	TCA D 22573	Scale from grid-wall junction, elevation 396 feet 1-1/2 inches.	41.2	15.8	24.4	6.2	0.21	12.3	-	-	-
2/22/73	TCA D 122273	Rust-colored scale from corroded demister.	3.6	4.2	83.2	0.0	-	9.0	-	-	-
2/12/73	TCA D 121273	Tar-like material from duct 25 feet downstream from reheater.	-	-	-	-	-	-	25.2 (27.3)	7.8 -	67.0 (72.7)
2/12/73	TCA D 221273	Tar-like material downstream from and near reheater.	-	-	-	-	-	-	39.3 (40.0)	1.7 -	59.0 (60.0)
Hydro-Filter System											
2/2/73	HFD-2273	Scale from corrosion spool above marble bed.	29.5	17.6	27.4	0.5	-	24.9	-	-	-
2/8/73	HFD-2373	Deposit from bottom slurry nozzle.	28.8	9.6	41.7	2.2	-	17.7	-	-	-
2/23/73	HFD-22373	Soot from gas duct about 25 feet above reheater.	-	-	-	-	-	-	36.4 (41.2)	11.7 -	51.9 (58.8)
General Operation Equipment											
3/1/73	3173	Scale from reslurry pump G-401.	39.8	0.54	12.8	20.1	-	26.7	-	-	-

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[a] Information taken from reports dated March and May 1973 by R. E. Wagner of inspections made February 1, 2, and 3, 1973 of the Hydro-Filter, the venturi, and the TCA scrubber systems.

[b] Values in parentheses are on a dry basis.

TABLE VI

Hardness of Neoprene Linings of Equipment in the Three Limestone - Wet-Scrubbing Systems for Sulfur Dioxide Removal from Stack Gas at Shawnee Power Plant

(Exposure period: Aug. 12, 1972, to Feb. 3, 1973)

Location of hardness test	Test temp., °F[a]	Durometer "A" hardness Original[b]	Final[c]
Venturi System (1840 Operating Hours)			
Afterscrubber Tower:			
Eight inches below Type 316L stainless steel at venturi section	-	60 to 65	67
Above trapout tray (approximate elevation 388 feet)	-	60 to 65	53 to 60
Three inches below mist eliminator	-	60 to 65	54 to 60
Three feet above mist eliminator	-	60 to 65	53 to 55
Four inches below Type 316L stainless steel duct to reheater	-	60 to 65	52 to 54
Clarified Process Water Storage Tank, D-103:			
Above liquid level	60	55 to 60	64 to 65
Below liquid level	60	55 to 60	61 to 63
Recirculation Tank:			
Five feet above bottom	-	55 to 60	65 to 69
Blades of agitator	-	60 to 70	63 to 67
Blades of Agitator In:			
Effluent hold tank D-101	-	60 to 70	65 to 66
Recirculation tank D-104	-	60 to 70	63 to 67
Pumps G-101, G-102, G-103, and G-104:			
Impellers and casings	-	54 to 56	60 to 70
New impellers and casings (spares)	-	-	64 to 72
TCA System (1667 Operating Hours)			
Scrubber Tower:			
Middle of wall and 6 inches below manway	-	60 to 65	55
Six inches above bottom grid (four walls)	60	60 to 65	58 to 60
Three feet above bottom grid near test spool 2006	-	60 to 65	59 to 63
Four feet below Koch tray	-	60 to 65	59 to 60
Two feet above Koch tray	-	60 to 65	53 to 55
Clarified Process Water Storage Tank, D-203:			
Above liquid level	60	55 to 60	62 to 71
Below liquid level	60	55 to 60	64 to 70
Recirculation Tank, D-204:			
Four and one-half feet above bottom	40	55 to 60	60 to 66
Blades of agitator	40	60 to 70	54 to 56
Blades of Agitator In:			
Effluent hold tank D-201	40	60 to 70	71
Recirculation tank D-204	-	60 to 70	54 to 58
Pumps G-201, G-202, and G-204:			
Impellers and casings	-	54 to 56	61 to 68
Hydro-Filter System (2203 Operating Hours)			
Scrubber Tower:			
Five inches below marble bed	36	60 to 65	68 to 72
Six inches above marble bed	36	60 to 65	70 to 71
Above demister and 6 inches below reducer	36	60 to 65	64 to 67
Three inches below Type 316L stainless steel stack	36	60 to 65	63 to 70
Clarified Process Water Storage Tank, D-303:			
Above liquid level	60	55 to 60	60 to 61
Below liquid level	60	55 to 60	58 to 60
Recirculation Tank, D-304:			
Five feet above bottom	-	55 to 60	75 to 80
Blades of agitator	-	60 to 70	67 to 70
Blades of Agitator In:			
Effluent hold tank D-301	40	60 to 70	63 to 66
Recirculation tank D-304	-	60 to 70	67 to 70
Pumps G-301, G-303A, G-303B, and G-304:			
Impellers and casings	35	54 to 56	52 to 68

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[a] Atmospheric temperature varied from about 35° to 60°F while tests for hardness were being made.

[b] Values not determined by TVA but were taken from information supplied to contractors for bidding on construction.

[c] The instrument used to determine the durometer hardness of neoprene linings during inspection of the plants (Feb. 1-3, 1973) was Shore "A-2," ASTM D2240. Note that the measurements were made over a wide range of temperatures; therefore, an exact comparison of hardness values is not possible. Usually three or more tests were made in an area.

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TABLE VII

Hardness[a] of Rubber Lining[b] Specimens Tested in the Limestone – Wet-Scrubbing Systems for Sulfur Dioxide Removal from Stack Gas at Shawnee Power Plant

(Exposure period—Aug. 12, 1972, to Feb. 3, 1973)

Location of specimens[c]	Durometer "A" hardness		
	Butyl (26,666)	Natural (1375)	Neoprene (9150)
As received	54–56 (55)	34–37 (35)	64–65 (64)
Venturi System (1840 Operating Hours)			
1008	56–58 (57)	39–40 (40)	60–63 (61)
1011	54–58 (56)	41–43 (42)	62–63 (62)
TCA System (1667 Operating Hours)			
2004	56–59 (57)	38–42 (40)	59–61 (60)
2008	54–58 (56)	36–39 (38)	59–64 (62)
Hydro-Filter System (2203 Operating Hours)			
3005	55–58 (57)	35–39 (38)	58–62 (60)
3008	54–58 (56)	37–40 (38)	61–65 (63)

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[a] Four tests were made of each specimen in the laboratory at 78°F with a durometer type "A2," ASTM D2240, manufactured by The Shore Instrument and Manufacturing Company. Values in parentheses are averages.

[b] Specimens of butyl, natural, and neoprene liners were applied on mild steel coupons by the Gates Rubber Company.

[c] See reference numbers on Figures 2–4.

TABLE VIII

Compilation of Corrosion Data of Materials Tested in the Three Limestone - Wet-Scrubbing Systems for Sulfur Dioxide Removal from Stack Gas at Shawnee Power Plant

Metals[d]	Cost comparison[b]		Corrosion[a]						
			On basis of weight loss, mils/yr, range	Specimens pitted			Specimens with crevice attack, No.	Specimens with other types of attack	
					Depth, mils[c]				
	A	B		No.	Minimum	Maximum		No.	Area
1. Hastelloy C-276	9.29	-	Neg. to 5	-	-	-	-	-	-
2. Inconel 625	6.59[e]	6.05	Neg. to 5	1	-	Minute	-	-	-
3. Incoloy 825	4.46[f]	3.73	Neg. to 7	-	-	-	1	-	-
4. Carpenter 20Cb-3	4.21	3.73	Neg. to 14	2	-	Minute	-	-	-
5. Type 316L SS	1.39	1.61	Neg. to 15	3	-	Minute	2	1, 1	G18[g], weld
6. Cupro-nickel 70-30	1.80[f]	-	< 1 to 49	1	-	18	-	1	Weld
7. Monel 400	2.93[f]	3.61	< 1 to 57	1	-	2	1	3	Weld
8. Hastelloy B	9.47	-	< 1 to 100	2	-	Minute	-	-	-
9. Type 446 SS	-	-	Neg. to 140	9	Minute	19	11	-	-
10. E-Brite 26-1	-	1.85	Neg. to 190	10	Minute	18	2	-	-
11. Incoloy 800	2.54	2.70	Neg. to 190	6	Minute	19	3	1	-[h]
12. USS 18-18-2	-	-	Neg. to 200	11	Minute	16	11	-	-
13. Type 304L SS	1.11	1.11	Neg. to 200	14	Minute	23	11	1	-[h]
14. Type 410 SS	1.92	0.93	< 1 to > 250	15	Minute	16	16	-	-
15. Aluminum 3003	-	-	< 1 to > 550	9	2	70	5	-	-
16. Mild Steel A-283	0.34[e], 0.80[f]	-	< 1 to > 1400	2	-	Minute	2	-	-
17. Cor-Ten B	-	-	< 1 to > 1400	5	Minute	3	4	1	Weld

Nonmetallic Materials	Condition		
	Good	Fair	Poor
Plastics			
1. Bondstrand 4000	12	-	9
2. Flakeline 200	2	14	5
3. Qua-Corr	5	-	1
Rubbers			
1. Butyl 26,666	6	-	-
2. Natural 1375	6	-	-
3. Neoprene 9150	6	-	-
Ceramic			
1. Transite	14	2	5

---

[a] The compilation is based on 21 tests of each material except for Qua-Corr and the three rubbers (butyl, natural, and neoprene) with which only six tests were conducted.

[b] Cost comparison values are based on Type 304 stainless steel having a value of 1.00. "A" is based on commercial quality tubing--10,000 feet of 3/4-inch outside diameter by 0.065-inch average wall which is cut to 20-foot 0-inch lengths. [Information from Carpenter Technology Corporation (August 7, 1973).] "B" is based on 1/8-inch sheet in 20,000-pound lots. [Information from J. M. Tull, Atlanta, Georgia, by telephone (July 2, 1973).]

[c] The actual depth of penetration in mils during exposure periods is indicated in Tables I, II, and III.

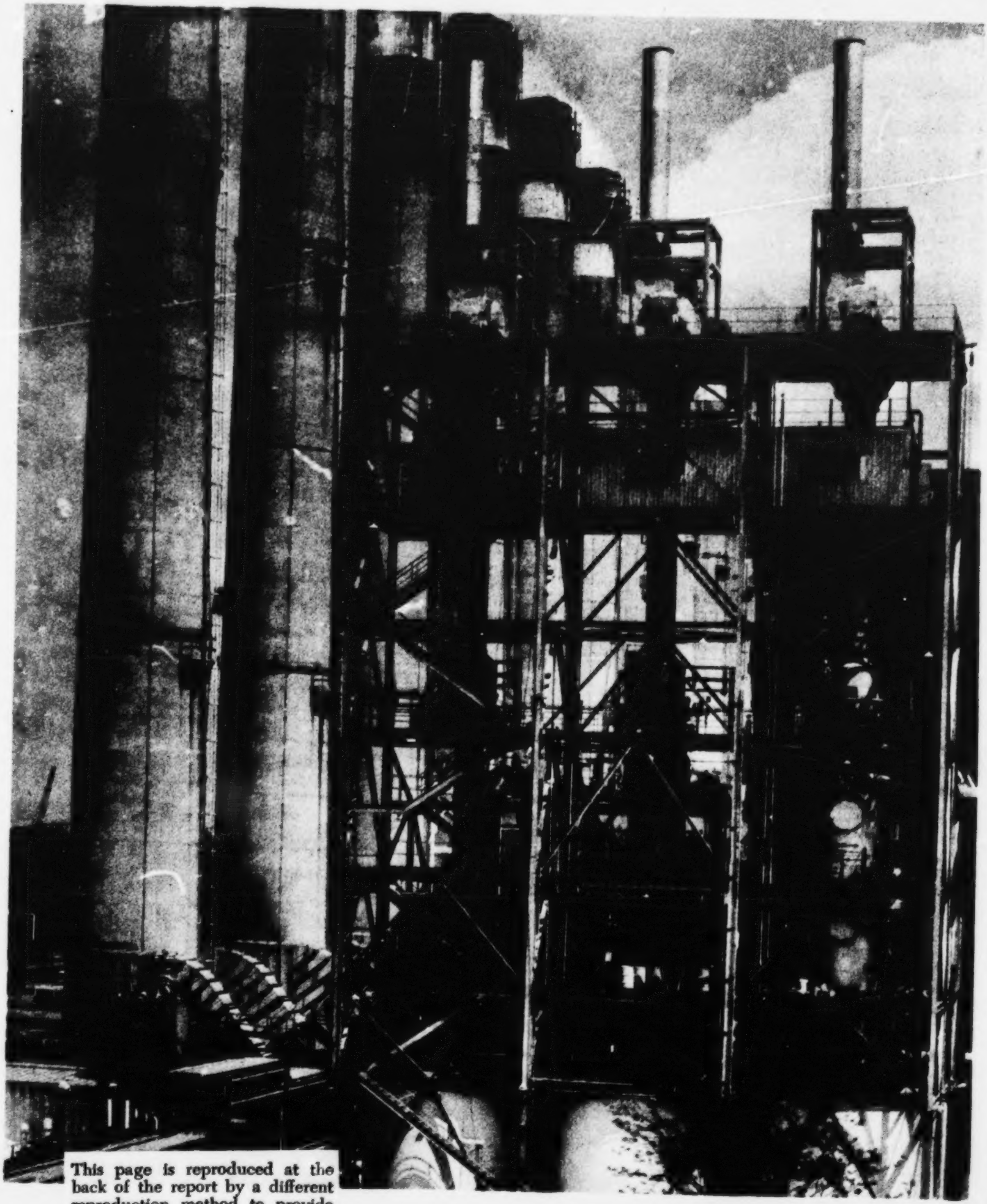
[d] Metals are listed in their approximate order of decreasing corrosion resistance.

[e] Welded.

[f] Seamless.

[g] A groove in parent metal was 18 mils deep.

[h] Severe localized attack of parent metal.



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HYDRO-FILTER
(FLOODED-BED
OF MARBLES)
TCA
(MOBILE BED OF
PING-PONG BALLS)
VENTURI
(FOLLOWED BY
AFTER-SCRUBBER)

FIGURE I
THREE PARALLEL SYSTEMS OF LIMESTONE-WET-SCRUBBING TEST FACILITY AT SHAWNEE POWER PLANT

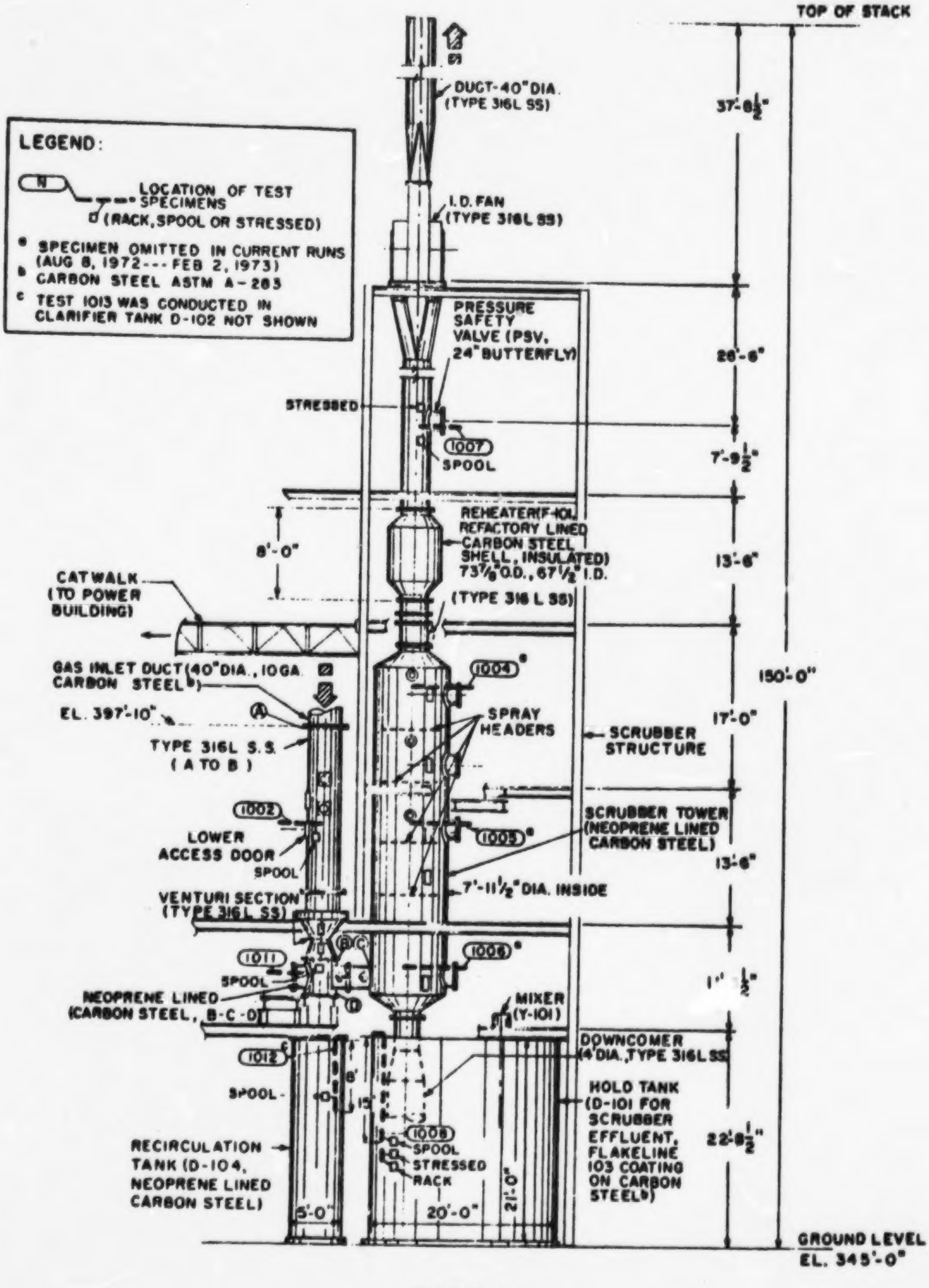
TOP OF STACK
DUCT-40" DIA.
(TYPE 316L SS)
37'-8½"
LEGEND:
N
LOCATION OF TEST SPECIMENS
(RACK, SPOOL OR STRESSED)
* SPECIMEN OMITTED IN CURRENT RUNS (AUG 8, 1972---FEB 2, 1973)
b CARBON STEEL ASTM A-283
c TEST 1013 WAS CONDUCTED IN CLARIFIER TANK D-102 NOT SHOWN
I.D. FAN
(TYPE 316L SS)
PRESSURE SAFETY VALVE (PSV, 24" BUTTERFLY)
26'-6"
STRESSED
1007
SPOOL
7'-9½"
REHEATER (F-101, REFACTORY LINED CARBON STEEL SHELL, INSULATED) 73⅞" O.D., 67½" I.D.
8'-0"
13'-6"
(TYPE 316 L SS)
CATWALK (TO POWER BUILDING)
GAS INLET DUCT (40" DIA., 10 GA. CARBON STEEL b)
1004 *
EL. 397'-10"
A
SPRAY HEADERS
SCRUBBER STRUCTURE
17'-0"
150'-0"
TYPE 316L S.S. (A TO B)
1002
LOWER ACCESS DOOR
SPOOL
SCRUBBER TOWER (NEOPRENE LINED CARBON STEEL)
1005 *
13'-6"
VENTURI SECTION * (TYPE 316L SS)
7'-11½" DIA. INSIDE
B
C
1011
SPOOL
1006 *
NEOPRENE LINED (CARBON STEEL, B-C-D)
D
1'' ½"
MIXER (Y-101)
DOWNCOMER (4' DIA., TYPE 316L SS)
1012 c
8'
SPOOL
15'
HOLD TANK (D-101 FOR SCRUBBER EFFLUENT, FLAKELINE 103 COATING ON CARBON STEEL b)
22'-8½"
1008
SPOOL
STRESSED
RACK
RECIRCULATION TANK (D-104, NEOPRENE LINED CARBON STEEL)
5'-0"
20'-0"
21'-0"
GROUND LEVEL
EL. 345'-0"

FIGURE 2
VENTURI SCRUBBER SYSTEM, (C-101)

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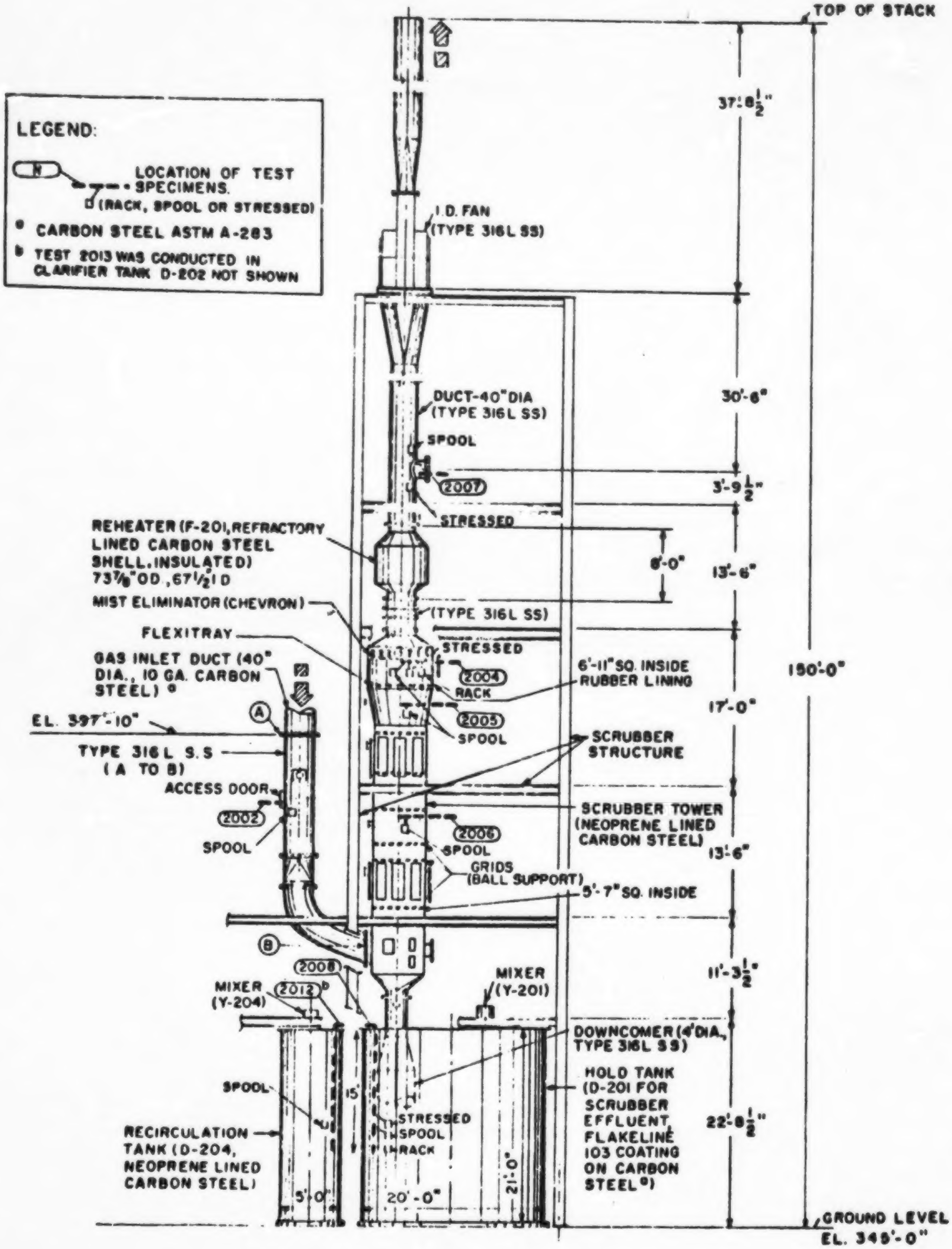
TOP OF STACK
LEGEND:
N
LOCATION OF TEST SPECIMENS.
(RACK, SPOOL OR STRESSED)
a CARBON STEEL ASTM A-283
b TEST 2013 WAS CONDUCTED IN CLARIFIER TANK D-202 NOT SHOWN
37'-8 1/2"
I.D. FAN (TYPE 316L SS)
30'-6"
DUCT-40" DIA (TYPE 316L SS)
SPOOL
2007
3'-9 1/2"
STRESSED
REHEATER (F-201, REFRACTORY LINED CARBON STEEL SHELL, INSULATED) 73 7/8" OD, 67 1/2 I D
8'-0"
13'-6"
MIST ELIMINATOR (CHEVRON)
(TYPE 316L SS)
FLEXITRAY
STRESSED
2004
RACK
6'-11" SQ. INSIDE RUBBER LINING
GAS INLET DUCT (40" DIA., 10 GA. CARBON STEEL) a
150'-0"
17'-0"
2005
SPOOL
A
EL. 397'-10"
TYPE 316L S.S (A TO B)
SCRUBBER STRUCTURE
ACCESS DOOR
2002
SPOOL
SCRUBBER TOWER (NEOPRENE LINED CARBON STEEL)
2006
SPOOL
13'-6"
GRIDS (BALL SUPPORT)
5'-7" SQ. INSIDE
B
2008
MIXER (Y-204)
2012 b
MIXER (Y-201)
11'-3 1/2"
DOWNCOMER (4' DIA, TYPE 316L SS)
HOLD TANK (D-201 FOR SCRUBBER EFFLUENT, FLAKELINE 103 COATING ON CARBON STEEL a)
SPOOL
15'
STRESSED
SPOOL
RACK
22'-8 1/2"
RECIRCULATION TANK (D-204, NEOPRENE LINED CARBON STEEL)
5'-0"
20'-0"
21'-0"
GROUND LEVEL EL. 345'-0"

FIGURE 3
TURBULENT CONTACT SCRUBBER SYSTEM, TCA-(C-201)
(MOBILE BED, -- PING-PONG BALL)

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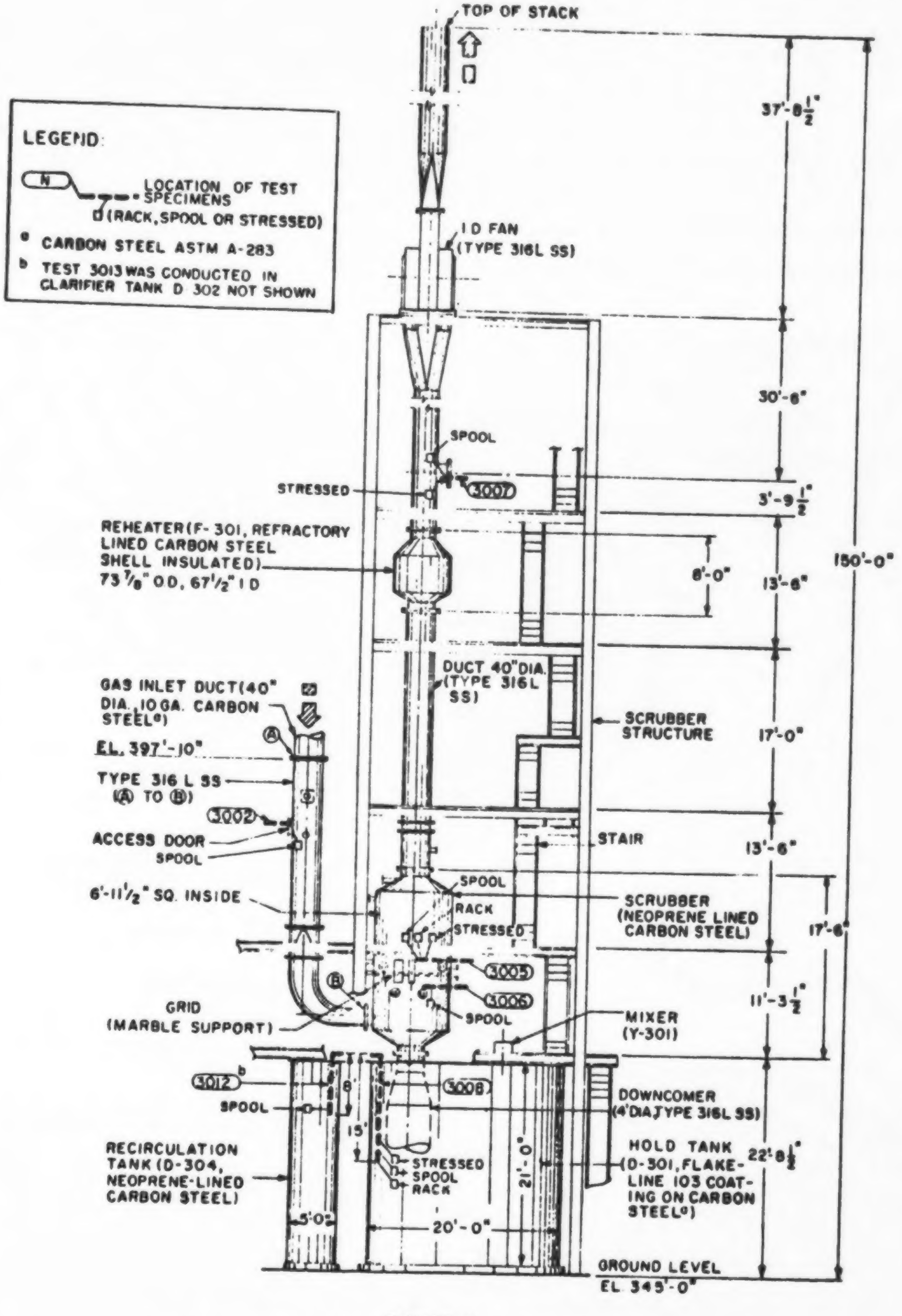
TOP OF STACK
LEGEND:
N
LOCATION OF TEST SPECIMENS
(RACK, SPOOL OR STRESSED)
a CARBON STEEL ASTM A-283
b TEST 3013 WAS CONDUCTED IN CLARIFIER TANK D 302 NOT SHOWN
I D FAN
(TYPE 316L SS)
37'-8 1/2"
30'-6"
SPOOL
STRESSED
3007
3'-9 1/2"
REHEATER (F-301, REFRACTORY LINED CARBON STEEL SHELL INSULATED)
73 7/8" O D, 67 1/2" I D
8'-0"
13'-6"
150'-0"
DUCT 40" DIA. (TYPE 316L SS)
GAS INLET DUCT (40" DIA. 10 GA. CARBON STEEL a)
A
EL. 397'-10"
SCRUBBER STRUCTURE
17'-0"
TYPE 316 L SS (A TO B)
3002
ACCESS DOOR
SPOOL
STAIR
13'-6"
SPOOL
6'-11 1/2" SQ. INSIDE
RACK
STRESSED
SCRUBBER (NEOPRENE LINED CARBON STEEL)
17'-6"
3005
B
3006
11'-3 1/2"
GRID (MARBLE SUPPORT)
SPOOL
MIXER (Y-301)
3012 b
8'
3008
SPOOL
DOWNCOMER (4' DIA. TYPE 316L SS)
15'
RECIRCULATION TANK (D-304, NEOPRENE-LINED CARBON STEEL)
STRESSED
SPOOL
RACK
21'-0"
HOLD TANK (D-301, FLAKE-LINE 103 COATING ON CARBON STEEL a)
22'-8 1/2"
5'-0"
20'-0"
GROUND LEVEL
EL. 345'-0"

FIGURE 4
HYDRO-FILTER SCRUBBER SYSTEM, HF-(C-301)
(FLOODED BED OF MARBLES)

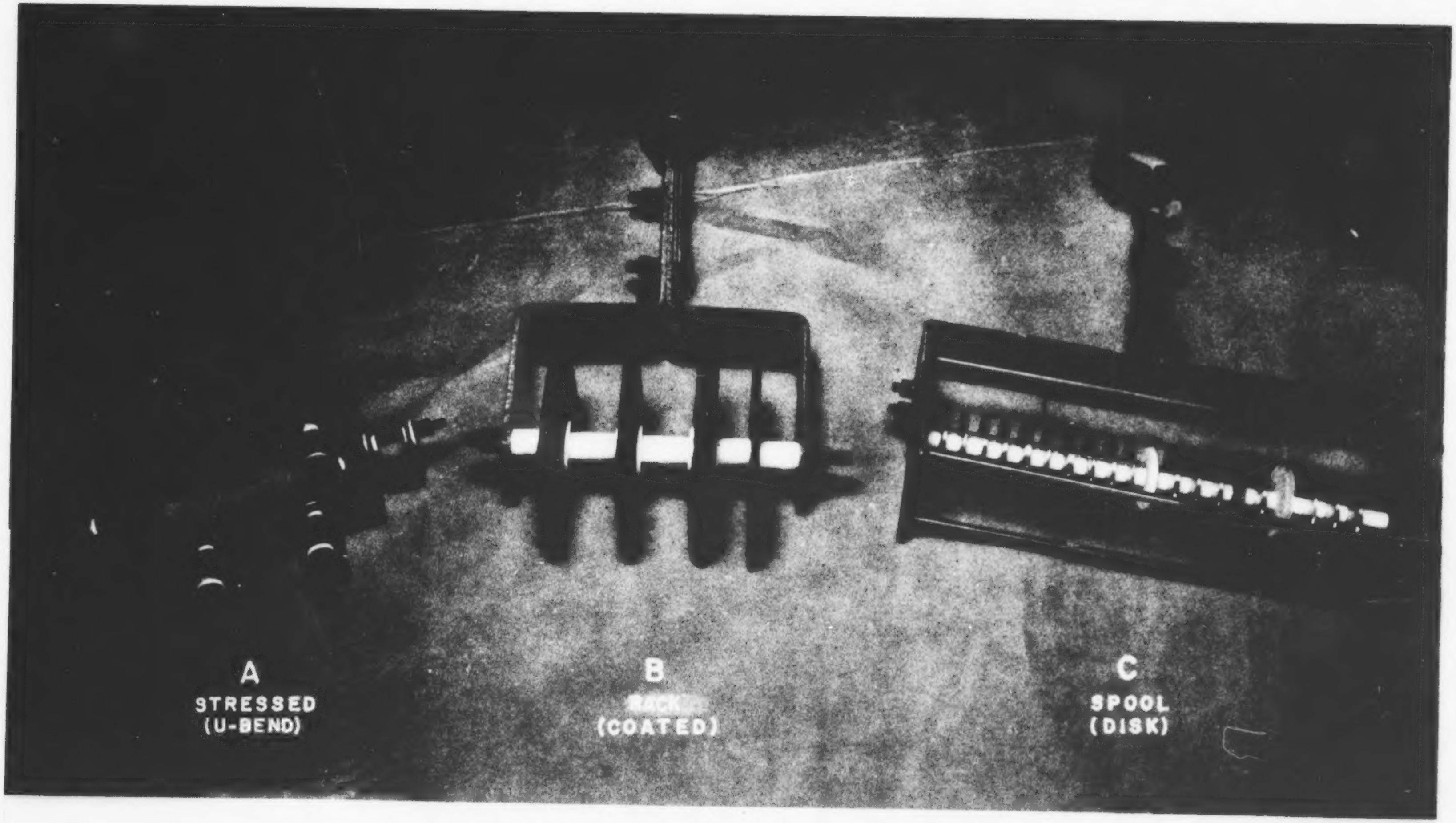
A
STRESSED
(U-BEND)
B
RACK
(COATED)
C
SPOOL
(DISK)

FIGURE 5
TYPICAL ASSEMBLIES OF CORROSION TEST SPECIMENS

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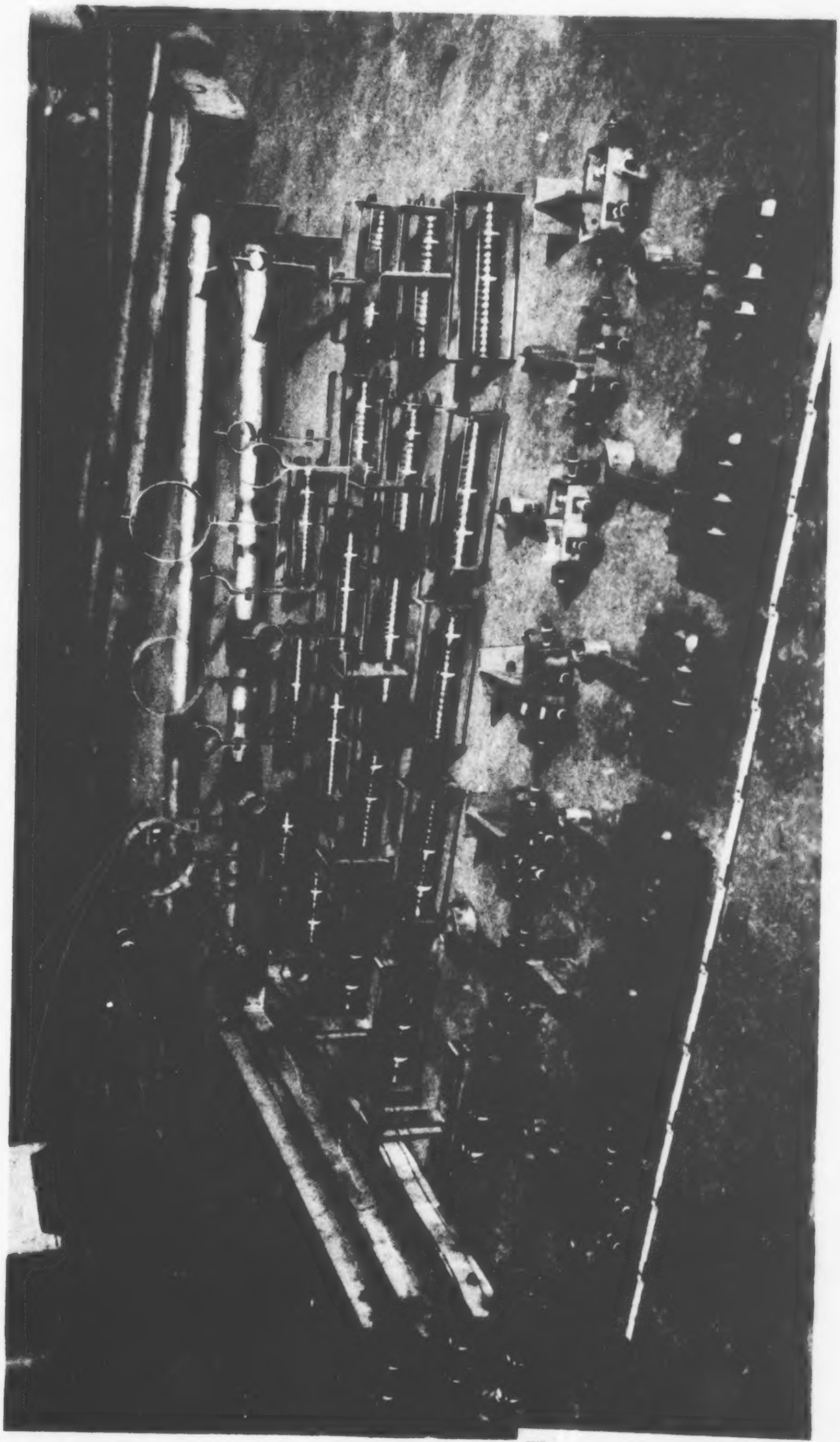

FIGURE 6

CORROSION TEST ASSEMBLIES AND SUPPORTS READY FOR INSTALLATION IN PLANTS

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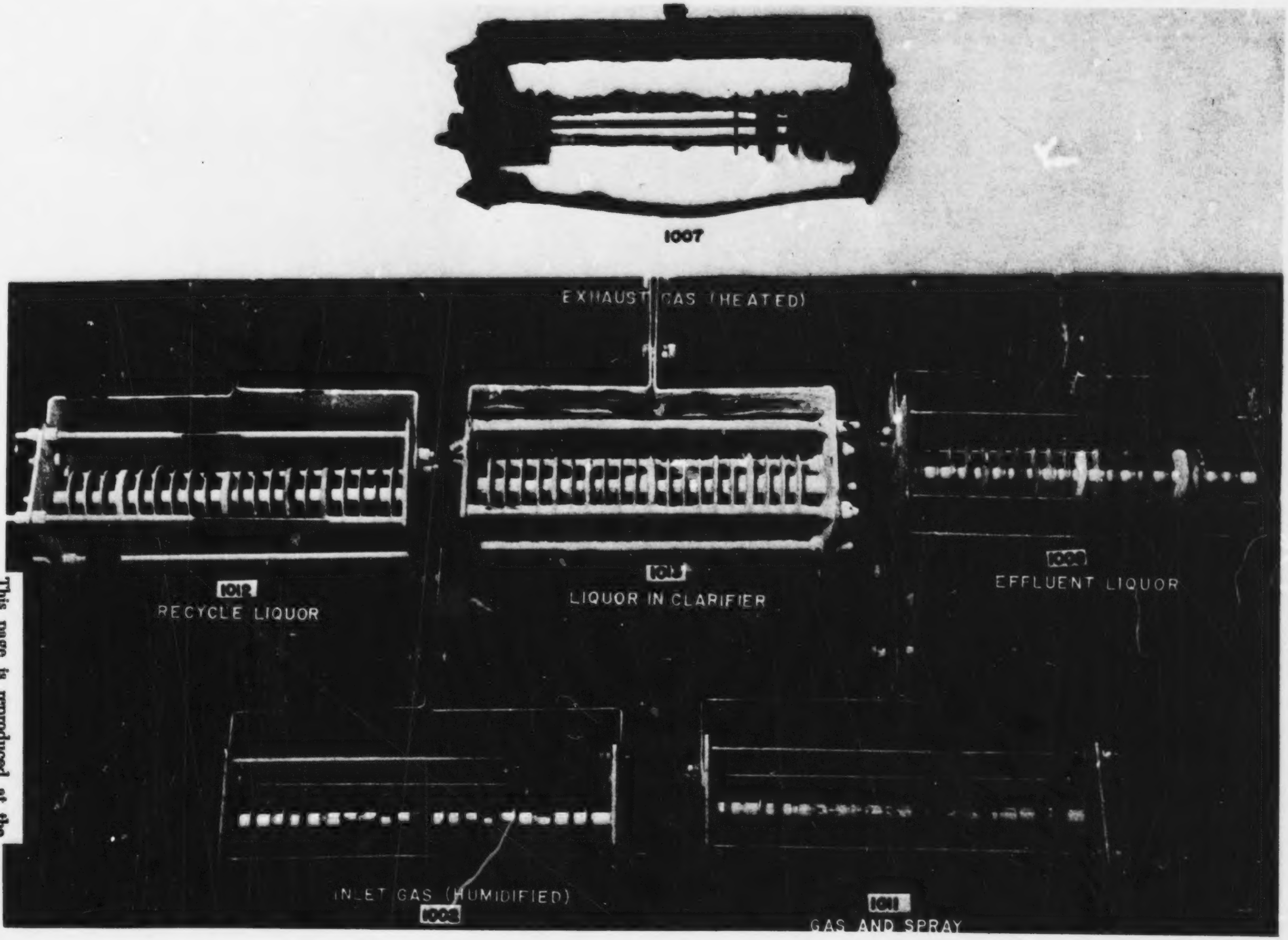
1007
EXHAUST GAS (HEATED)
1012
RECYCLE LIQUOR
1013
LIQUOR IN CLARIFIER
EFFLUENT LIQUOR
INLET GAS (HUMIDIFIED)
1008
1011
GAS AND SPRAY

FIGURE 7
DISK SPECIMENS AFTER EXPOSURE IN VENTURI SYSTEM (AUG. 12, 1972--FEB. 2, 1973)

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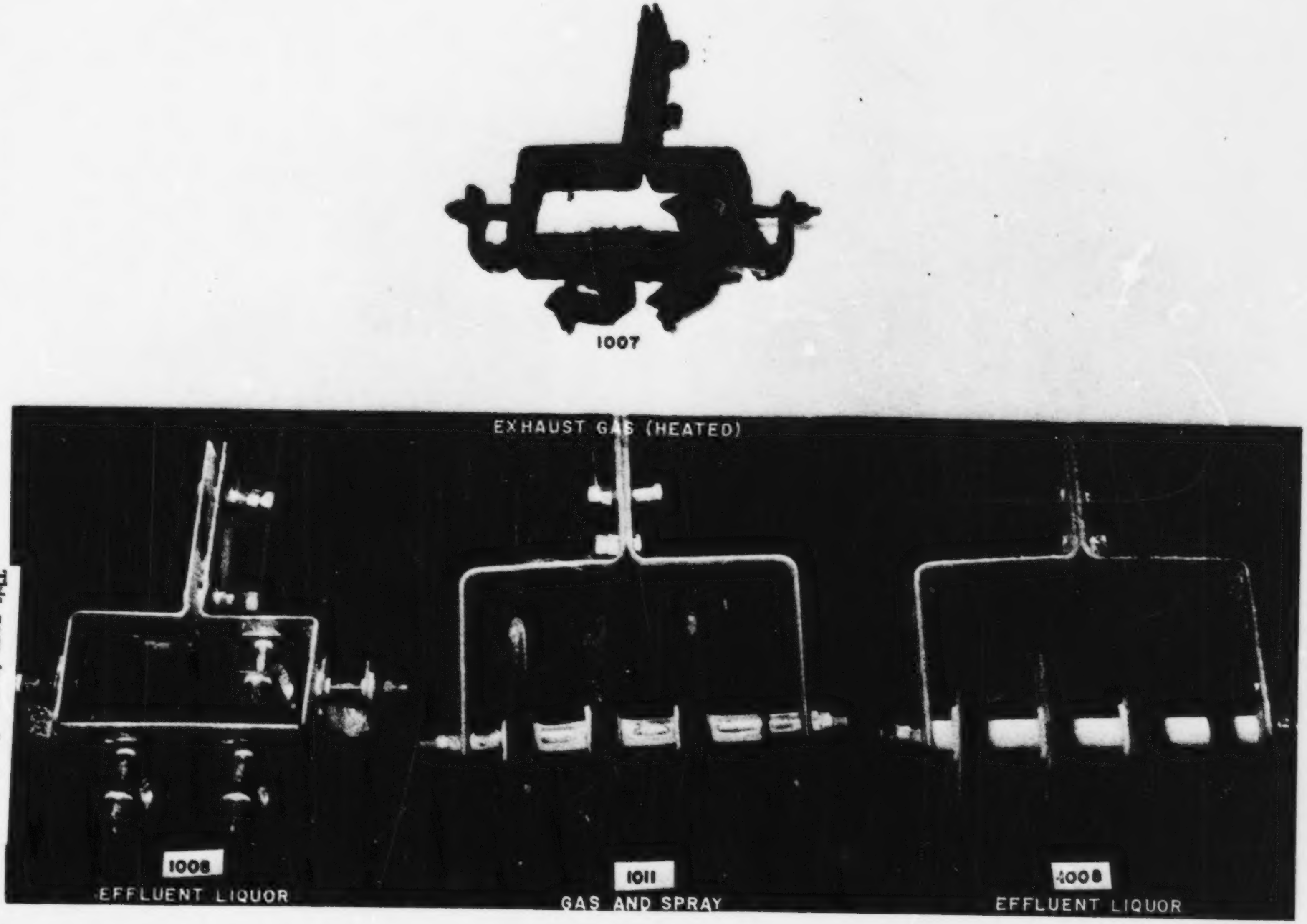
1007
EXHAUST GAS (HEATED)
1008
EFFLUENT LIQUOR
1011
GAS AND SPRAY
1008
EFFLUENT LIQUOR

FIGURE 8
STRESSED AND COATED SPECIMENS AFTER EXPOSURE IN VENTURI SYSTEM
AUG. 12, 1972-- FEB. 2, 1973

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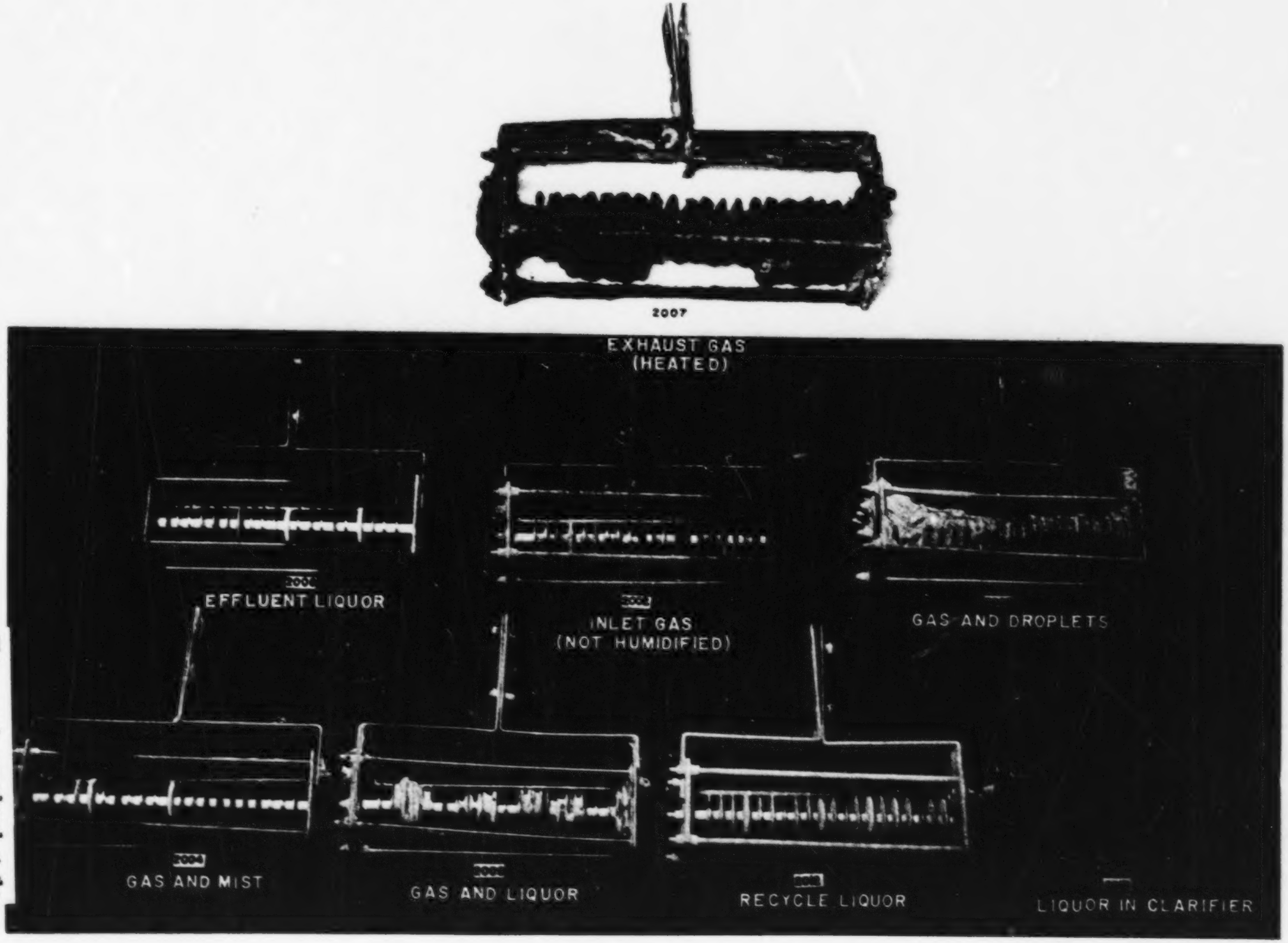
2007
EXHAUST GAS
(HEATED)
EFFLUENT LIQUOR
INLET GAS
(NOT HUMIDIFIED)
GAS AND DROPLETS
GAS AND MIST
GAS AND LIQUOR
RECYCLE LIQUOR
LIQUOR IN CLARIFIER

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FIGURE 9
DISK SPECIMENS AFTER EXPOSURE IN TCA SYSTEM (AUG. 12, 1972--FEB. 3, 1973)

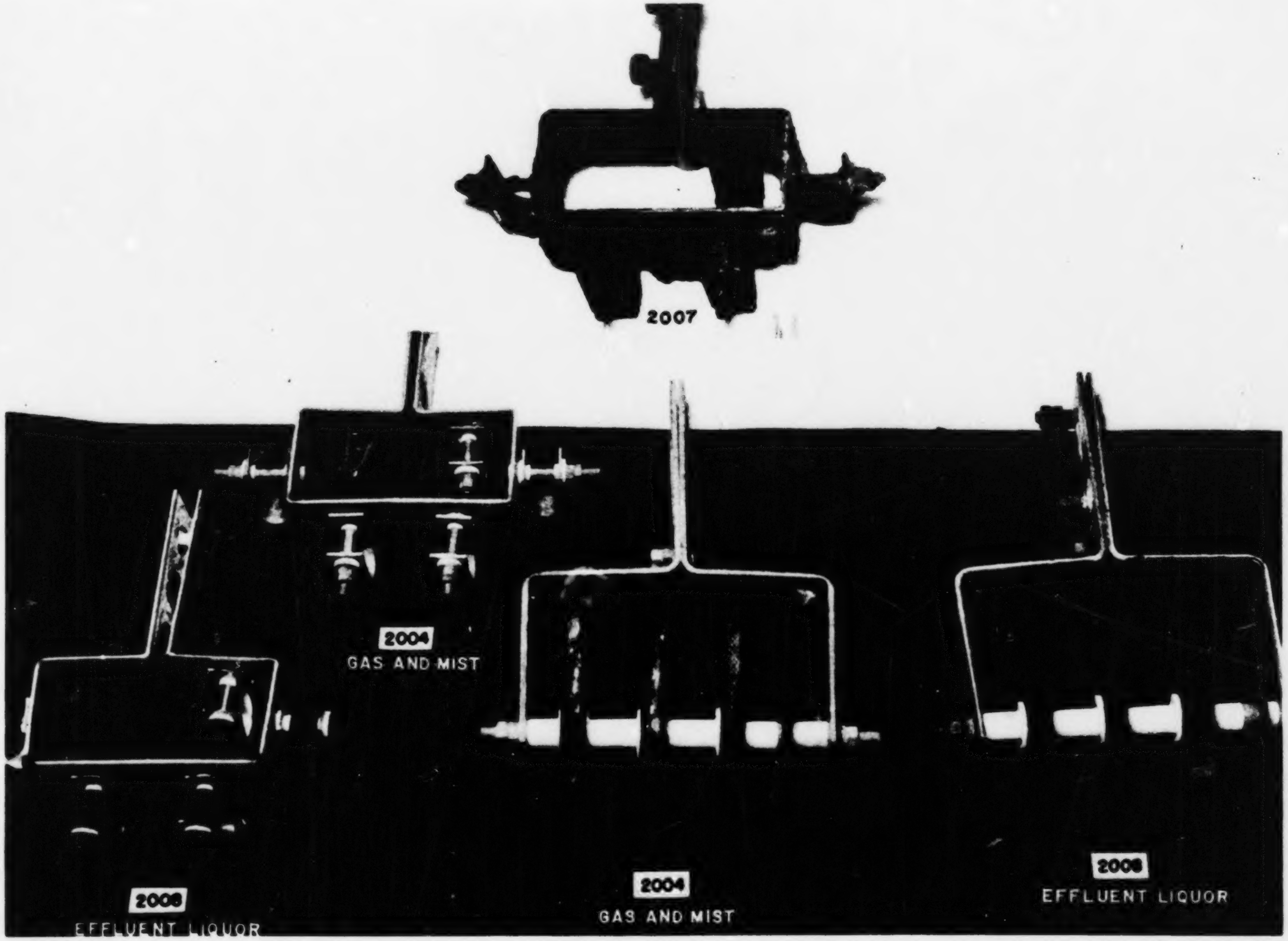
2007
2004
GAS AND MIST
2008
EFFLUENT LIQUOR
2004
GAS AND MIST
2008
EFFLUENT LIQUOR

FIGURE 10
STRESSED AND COATED SPECIMENS AFTER EXPOSURE IN TCA SYSTEM
AUG. 12, 1972-- FEB. 3, 1973

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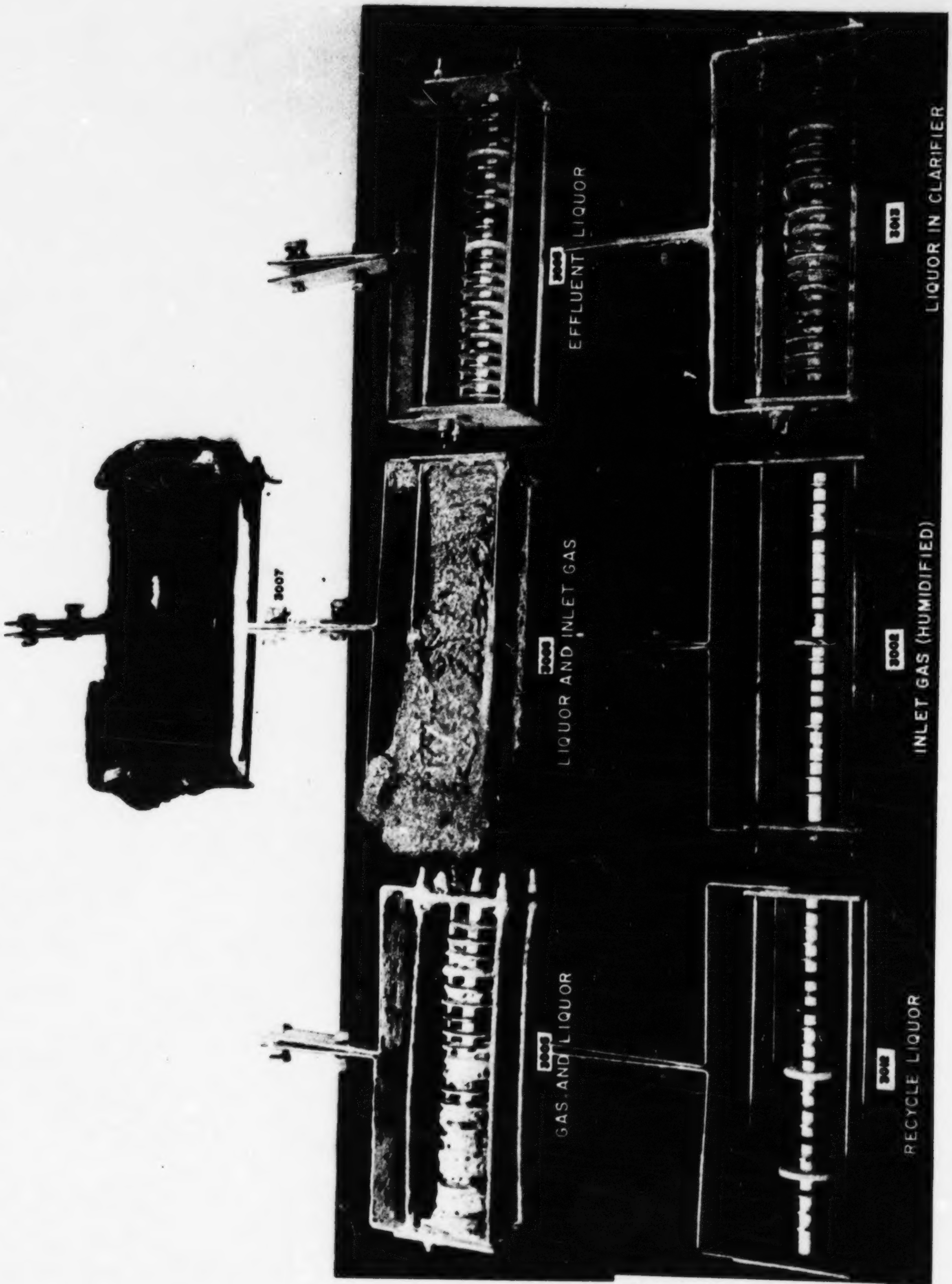

GAS AND LIQUOR
RECYCLE LIQUOR
3007
LIQUOR AND INLET GAS
INLET GAS (HUMIDIFIED)
EFFLUENT LIQUOR
LIQUOR IN CLARIFIER

FIGURE 11
DISK SPECIMENS AFTER EXPOSURE IN HYDRO-FILTER SYSTEM (AUG. 12, 1972--FEB. 1, 1973)

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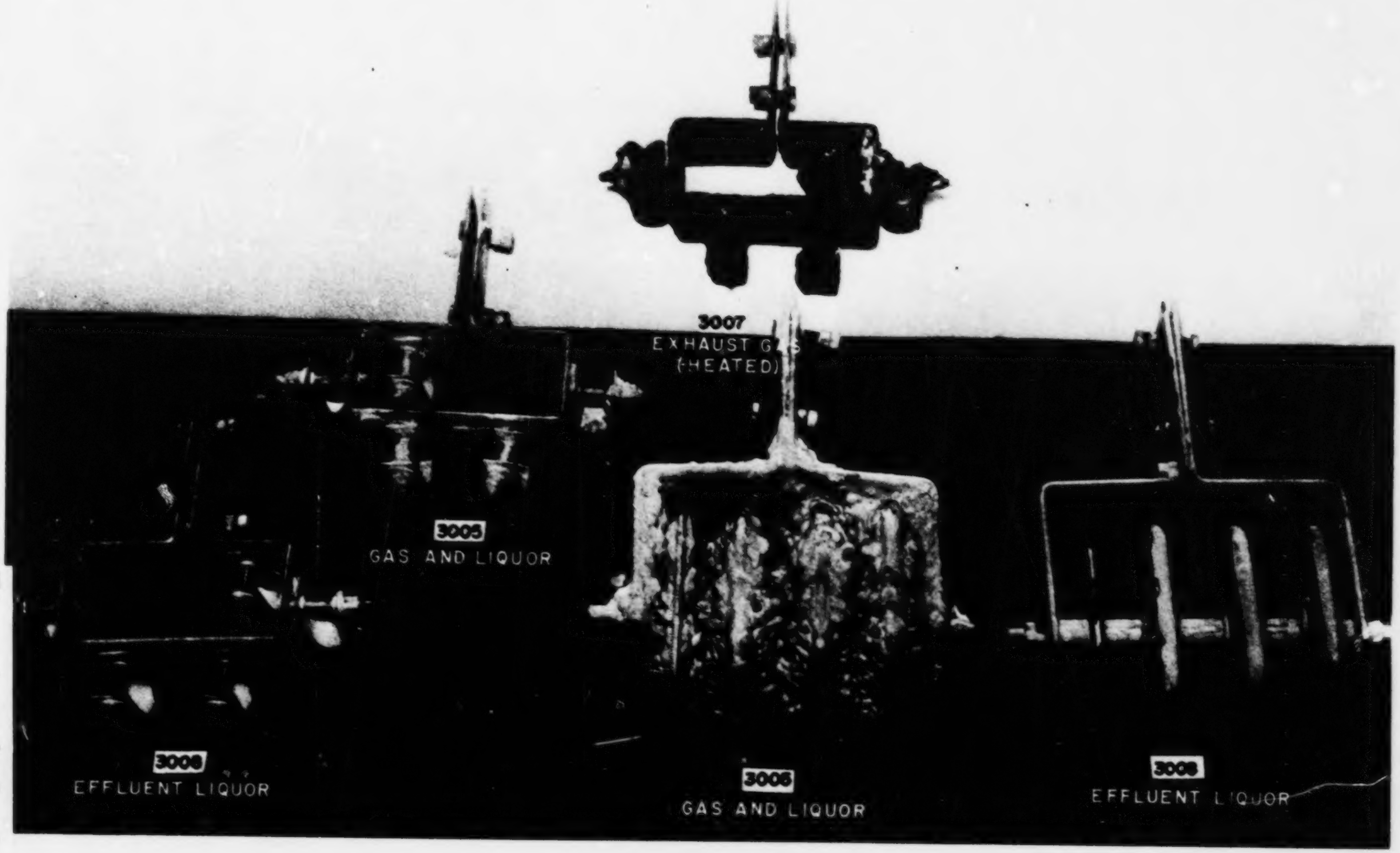
3007
EXHAUST GAS
(HEATED)
3005
GAS AND LIQUOR
3008
EFFLUENT LIQUOR
3006
GAS AND LIQUOR
3008
EFFLUENT LIQUOR

FIGURE 12
STRESSED AND COATED SPECIMENS AFTER EXPOSURE IN HYDRO-FILTER SYSTEM
AUG. 12, 1972-- FEB. 1, 1973

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